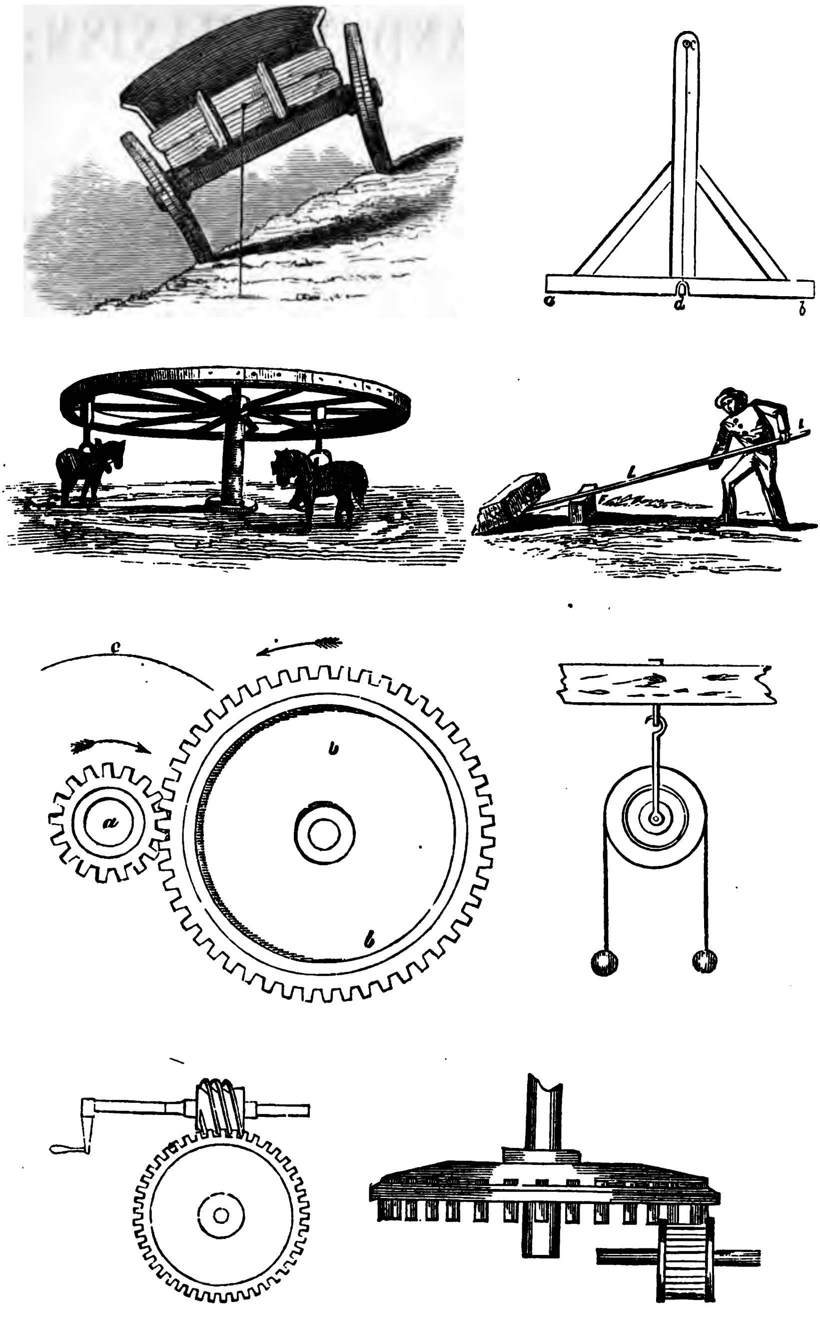

MECHANICS
AND
MECHANISM



FRONTISPIECE.

MECHANICS AND MECHANISM:

BEING

Elementary Essays and Examples

FOR THE USE OF

SCHOOLS AND STUDENTS.

UPWARDS OF 200 ILLUSTRATIONS.

EDITED BY

ROBERT SCOTT BURN,

EDITOR OF

"THE ILLUSTRATED DRAWING-BOOK;" "THE STEAM-ENGINE: ITS HISTORY AND MECHANISM;" "PRACTICAL GEOMETRY;" "ARCHITECTURAL, ENGINEERING, AND MECHANICAL DRAWING-BOOK;" "ORNAMENTAL AND ARCHITECTURAL DESIGN," &c.

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PREFACE TO THE THIRD EDITION.

IN preparing a new edition of "Mechanics and Mechanism," the Editor has availed himself of the opportunity to revise the whole carefully; to correct errors and expunge crudities which encumbered the previous editions, and to insert additional illustrations of mechanical movements and construction, wherever these have seemed necessary to further elucidate the text, or add to the interest of the work. In its improved form the Editor ventures to hope that the work will secure that large share of public patronage which favoured the first issues.

R. S. B.

December, 1857.

PREFACE TO THE FIRST AND SECOND EDITIONS.

A WORK, like the present, treating exclusively on "Mechanics and Mechanism," and forming part of a Popular Educational Series, would, at a period not very remote in our social history, have been looked upon as an innovation, and considered to be, upon the whole, as useless as it appeared strange and uncalled for. And this view, singular as it may now appear, would have been founded upon a comparatively correct estimate of the importance of the subject. Mechanism then occupied but a very subordinate position in the ranks of our social powers, and mechanicians were as few in numbers and unimportant in influence as were their works and labours. Now, however, the position of affairs is singularly changed. "Mechanicians—and mechanism, the emanations of their genius—" as we have elsewhere remarked, "occupy an important position in our social and commercial system. It is now scarcely, if at all, an exaggeration to affirm that, to the improvements recently effected in the various branches of the mechanical arts we owe our present position as a nation. The steam-engine, and the powers it gave us, enabled us to cope successfully with the otherwise overwhelming disadvantages which a long and expensive war entailed upon us. To mechanism we owe the factories from which we send out our cloths to supply the world's markets; to mechanism we owe that giant power which, with equal facility, propels our ships in the ocean storm, as in the calm waters of our inland rivers. It is mechanism, well arranged and modified, which whirls the traveller along the iron way with an untiring speed which the swiftest race-horse bred by man can never rival; it is mechanism, finely constituted and cunningly devised, which forms the plainly useful as well as the beautifully elegant of our numerous and varied fabrics; in fact and in short, there is scarcely an article we use but what owes its production to one of the many combinations of mechanism. Nothing to the accomplished mechanician comes amiss; constructing the simple mechanism which effects a single purpose with ease, he as freely masters that which is imitative of operations which, apparently, nothing less than human skill could execute or human brains dictate. No matter what the operation to be effected: let it be complex in its details, to a degree stultifying to an ordinary mind, no sooner is it

required than machinery is devised and set to work; and the operation is effected apparently with as much ease as the forms are made which constitute written language by the pen of the ready writer, or the throwing of the shuttle in the weaver's hand-loom." Seeing, then, the important part played in all our social movements by the mechanic, using the term in its widest acceptation, we think that it is scarcely necessary to dilate as to the expediency of imparting a knowledge of the elements of mechanics and mechanism to the rising generation. A nation which owes so much to the results of these powers should not, in its schemes of education, ignore the necessity of explaining their principles, or adopt a system of instruction in which this important subject is altogether overlooked. As mathematics are said to impart a healthy invigorating tone to the reasoning faculties, so the study of mechanics, in like manner, may be said to teach directly the value of system, and the advantages of "doing the right thing in its right place." We are scarcely prepared to go the length of an eminent engineer, whose opinion was, that if all were taught "mechanics" generally, not with reference to the following out of any distinct profession or calling, they would perform their various duties quicker and with greater ease to themselves; and that even females, if possessed of this knowledge, would make better housewives: nevertheless, we conceive there is much truth in the idea, which would become more apparent if generally acted upon. Not further to go into the benefit to be derived from the study of mechanics, we shall proceed to explain briefly the nature of our present treatise, and the method we have adopted in its treatment.

The work is essentially popular, and we may add practical; we have given results and arrangements only, refraining from an exposition of those strictly theoretical rules and mathematical formulæ which serve, in many instances, to confuse rather than to enlighten, to deter rather than induce the pupil to proceed. Not that we deem this theory, and that mathematical formula useless or unnecessary; but we have so frequently been impressed with the benefit to be derived, in the study of *mechanical arrangement and construction*, from separating the purely theoretical from the purely practical, that we have determined to adopt in this work the principle of giving only practical arrangements and their results.

Thus, supposing a pupil desirous of becoming acquainted with the arrangement by which the rectilineal motion of a steam-engine piston-rod is changed into the circular one of the fly-wheel, we proceed to explain, in the first instance, how this change is produced; but instead of giving a theoretical exercise, or entering into an exposition of the nature of the acting force at various points in the revolution of the crank, or the estimated loss entailed by its use, we suppose the pupil desirous of knowing the actual details of its construction. Thus he will at once *ceive from our explanation*, how pieces of thin iron-wire may produce

the desired movement; but this would not explain the method by which *mechanics in actual practice* availed themselves of the principle. We proceed therefore to explain how a crank is actually made, what is its form, how it is fixed on the shaft, what constitutes a connecting-rod, how it is constructed, how connected with the crank; in short, the arrangement of the various parts and how fitted together, as exemplified in *actual working machinery.* Again, in describing the nature and uses of a shaft, we first give an explanation of its distinguishing features and how it may be used; then divide it into its component parts, explain their actual construction, the method of making the journals on which they revolve, and the means of reducing the friction of their revolutions. Our work may therefore be considered introductory to those more abstruse treatises which enter into theoretical disquisitions, showing how the parts should be proportioned to insure proper strength, without undue outlay of material, and which elucidate the theory of mechanical movements and the principles of mechanical construction.

All the explanations we attempt to carry out in such a manner that the pupil, after studying them, could point out the various parts of an actual machine, and say, "this is a pedestal, that a cottar; these brasses are made to embrace this crank-pin by such a means; this is made in such a manner, that so secured; this motion is produced, and that changed, reversed, or altered by these various arrangements." But, not satisfied with these explanations merely, we suppose the pupil anxious to become acquainted with the *preliminary operations or processes* which must be gone through before the various movements can be made available for practical use. We then proceed to explain these processes: how this part is made circular, and what the means employed, thus necessitating an explanation of the turning-lathe; how this aperture is produced, thus involving the explanation of boring tools and machines; how this surface is made smooth, the chisel and planing machine being then described; and so on throughout the whole range of operations of the machine-shop. From this exposition, the reader will at once perceive the distinguishing feature of our present treatise. It is not designed to serve as a guide to the practical mechanic, to enable him to proportion the various parts of his machines according to correct theory, or to assist him in drawing up his calculations; but as a means of giving a ready insight into the constructive forms and arrangements of general mechanism, as well as the methods by which the movements are produced, we venture to hope that our treatise will present some claim to be considered as a useful auxiliary in an educational series. The rapidity with which the first large edition was exhausted, may be taken as an evidence that this hope is well founded. We have aimed at using the simplest language, avoiding the use of technicalities as far as the nature of the subject would admit of. We have endeavoured to give a consecutive

arrangement to the various departments, placing these, as far as possible, in the order of their general sequence. The illustrations, unsparingly given, will render the text, it is hoped, easily understood. For a considerable portion of the first three chapters, the reader is indebted to the pen of an able and pleasing writer, Eneas Mackenzie, Esq., author of several popular educational works.

To the reader anxious to go into the study of the action of various machines, as well as the theory of their construction, we cordially recommend the perusal of *The Engineer's and Machinist's Assistant*, published by Messrs. Blackie, of Glasgow and London; and the large work of Buchanan on Mill-work, with two volumes of plates, edited by Sir John Rennie, and published by Weale, of London. These, though expensive, will be of eminent service to those of our readers who may be contemplating the following out of professions in which the theory as well as the practice of mechanics is desiderated. A knowledge of the current inventions of the day, and of the progression of practical mechanics as applied to labour-saving conveniences, may best be derived from an examination of the pages of those valuable mechanical journals, *The Artisan*, *The Practical Mechanic's Journal*, *The Mechanic's Magazine*, and the *Patent Journal*, all of which abound with very interesting and valuable information. To the pages of some of these we have been, in one or two instances, indebted for illustrations of mechanical movements recently introduced; for the great majority of our examples, however, we are indebted either to a practical acquaintance with the subjects, or to sources available through a business connection.

In concluding, it may be necessary to state, that we have not gone so deeply into the mechanical details of the steam-engine as at a first glance at the following pages might be considered essential, inasmuch as we have fully explained these details in a special volume entitled, *The Steam-Engine, its History and Mechanism.*

R. S. B.

March, 1854.

MECHANICS AND MECHANISM.

CHAPTER I.

THE CENTRE OF GRAVITY.

EVERY atom of matter is equally attracted to the earth. When the atoms form a solid, they cannot separately act, but as it were concentrate the whole weight of the body at a point which, if supported or suspended, will balance, hold in equilibrium, or keep in a state of rest, the entire mass: this point is called the *centre of gravity*, *centre of inertia*, or *centre of parallel forces.*

If a stick be laid across a finger, one particular part will be found where it will balance and remain at rest; that part is the centre of gravity in the stick. The bulk and density on both sides of this point of the stick will be equal; and thus by a sufficient support at this part the attraction of the earth is successfully resisted, for in any other position the stick would fall to the ground. The centre of gravity appears, then, to be the point which seeks the lowest level, and exists in everything, of whatever shape it may be, in the universe.

By lifting a solid body at this point, the whole is lifted; or by preventing this part being moved, the mass is at rest.

A rod of iron having equal quantities of matter throughout its length will have its centre of gravity exactly in the middle. If a piece of wood or any other substance in the shape of a triangle be hung up from two points so as to swing freely, a string with a plummet attached will exactly cut the triangle in two from each point; and the point where the lines cross each other will be the centre of gravity. By marking the lines with a pencil or piece of chalk, the exact spot can be found. Any irregular-shaped thing, as a painter's palette, fig. 2, freely suspended from different parts, will have the plummet-line crossing at one point, which is the centre of gravity.

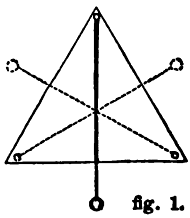


fig. 1.

A line drawn from the centre of gravity direct to the earth is called the *line of direction.* This is only an imaginary line, but one of great importance in the concerns of life; for if a square or

angular figure be placed upon the ground, and this line does not fall within its base, it will fall over. This is most clearly illustrated in the case of a

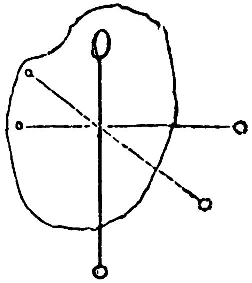


fig. 2.

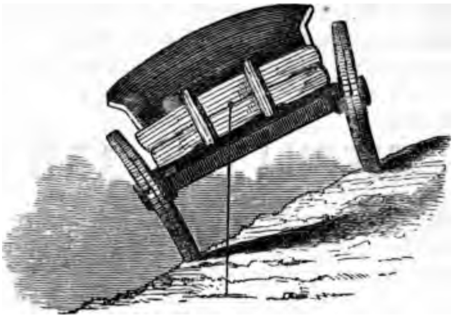


fig. 3.

loaded cart. Suppose a cart (see fig. 3) having lead or iron in it, passing along an uneven road, by which one wheel is raised much higher than the other, and the centre of gravity be at the part marked at the back of the cart, then the line of direction falls within the wheel, and the cart will not upset: but if it be so loaded, as is often done, with hops or wool (fig. 4), then the centre of gravity is moved much higher up; and the line of direction falling outside the wheel, which in this case is the base, the cart will turn over. Thus, then, the nearer the centre of gravity is to the base, and the line of direction in its middle, the steadier an object is. This is what gives snch permanence to those colossal erections of the ancient Egyptians, the Pyramids.

fig. 4.

A ship at sea will upset in a squall, from not having sufficient ballast; so that the centre of gravity must be low down, to counterbalance the weight of masts and rigging; while if the vessel be loaded only close to the keel, it rolls about most unpleasantly. Boys amuse themselves by taking a piece of pith of the alder-tree, and sticking in at one end a brass round-headed tack, when, laying it on its side and removing the finger away, it starts upright. In obedience to the same principle, a loaded ship recovers itself from a squall of wind.

The amusing toys for children called Chinese tumblers—semblances of little pink-eyed, cunning-looking Chinamen; or broad-faced, bluff, laughing Englishmen; or careful, affectionate mothers with babes in their arms—have broad heavy bases, and when placed on the ground, roll and rock until they have attained a straight position, always starting up when

laid on their sides, smiling at their cunning, laughing at the fun, or pleasingly rocking the child to rest.

In a steamboat having the deck laden with passengers, as seen often on the Thames, the greatest cause to anticipate an accident lies in some event occurring from which the people might start upon their feet, and rush to one side of the vessel; when the centre of gravity being changed, it would capsize, and the pleasure-seeking crowd be launched into the stream.

Accidents in boats are of continual occurrence, in consequence of people, instead of being steady or lying at the bottom of a little bark, rushing to one side on the slightest cause for fear, and thus creating the very mischief they desired to avoid.

In a round ball equally made, the centre of gravity is in the middle; the base of all round bodies being a mere point. This is what makes them moved with little force, so that even a gust of wind whirls them along a smooth surface.

A round body placed on a slope or inclined plane rolls rapidly down, and a square one slides to the bottom, because the centre of gravity is beyond the base. If a round cylinder of light wood be placed on an inclined plane, and a piece of lead be inserted near the periphery and upper part of the roller towards the rise of the inclined plane, then the cylinder may be seen to roll up the steep; this will only happen, however, when the lead is heavy enough to overcome the force of gravity, which tends to make the ball roll down the plane.

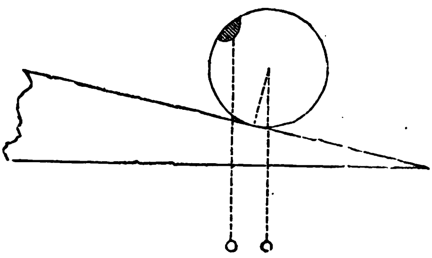


fig. 5.

In fig. 5 it will be seen that the line of direction pointed out by the plummet-line nearest the end of the inclined plane hangs over the base of the cylinder, consequently it would roll downwards; by the insertion of the lead the centre of gravity is moved, and the line of direction is on the other side of the base, which makes the body roll up the slope. It is on this principle that men aid a carriage or cart uphill by stepping on the spokes; their weight moving the centre of gravity of the wheel, astonishingly assists the exertions of the horses.

If two smooth pieces of iron with planed faces, *a b*, be placed close at

fig. 6.

one end and separated at the other, but raised, and a double cone *c* be put at the narrow end, it will roll along apparently upward. This is from

the tapering ends of the cone finding room between the separated pieces of iron, and the heavy middle part, or centre of gravity, really approaching nearer to the earth.

It is a common trick to offer to balance a poker, a pail of water, or a weight, from a piece of wood projecting over a table. It will immediately be perceived, fig. 7, that the weight *w* would fall to the ground if the cord *a*, to which it is attached, were allowed to hang straight; but by placing a piece of wood *b* reaching to the end of the stick, the weight is pushed to one side, and its centre of gravity is underneath the table: thus both the stick and weight are supported by it. The reason of this is, if the stick to which the weight is suspended fell, the weight must rise upward towards the table; but being heavier than the stick, this cannot take place, therefore it remains at rest.

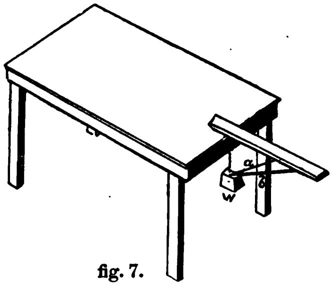


fig. 7.

The mason and the bricklayer, at every addition they make to the height of their work, use the plumb-rule to see that the wall is straight; for if it leaned inward or outward, it would be apt to tumble down: the importance of attention to the centre of gravity is thus seen. The annexed figure (8) represents the mason's level. The under side *a b* is placed on the wall; if the cord by which the weight *d* is suspended from *c* hang so as to correspond with a line on the centre of the upright, the wall on which *a b* rests is level.

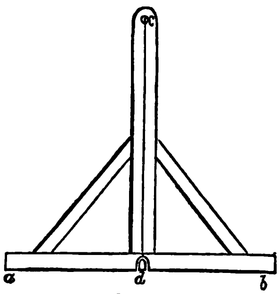


fig. 8.

The celebrated belfry, or round tower, at Pisa in Italy, incased with marble, is 190 feet high, and leans to one side twelve feet at the top beyond the foundation; but the line of direction is within the base; and therefore, as long as the cement endures, it will safely stand to astonish and frighten the gazing traveller.

At Bologna there is a tower 134 feet high, having an inclination of nine feet from the perpendicular, yet it stands firmly for the same reason that applies to the Pisa tower.

In scale-beams the centre of gravity is made in the same place as the centre of motion, from which arises the utility of the machine, as it will rest according as it may be adjusted by the placing of weights and materials upon each side.

Rope-dancers, that they may balance themselves on a narrow foundation, sometimes use a long pole loaded at each end with lead; this they hold across the rope, and fixing their eyes on some object, perceive when their centre of gravity tends either to one side or the other, which they recover by a movement of the pole, and thus keep the centre of gravity over the base.

Among other devices of itinerants to gain a precarious livelihood is that of dancing on stilts, imitating the unstable and fearful rollings of a drunken man, and hopping about on one long leg or pole: this is all most *cleverly performed* by a due attention to preserving the centre of gravity.

When a person stands on one leg, the other leg is held up behind to adjust the centre of gravity. This is most beautifully shown in the statue of Mercury, which is poised on the toes of one foot, while the other is elevated behind. The opera-dancers, in their exhibitions of the "poetry of motion," while raised on one foot and the body leaning forward, balance themselves by raising the other in such a manner as to preserve the centre of gravity over that part touching the ground.

On ascending stairs the body is bent forward, that the centre of gravity may progress with the feet.

When seated, the centre of gravity is on the seat; therefore when we rise, the feet are drawn in and the body forward, that the centre of gravity may be in a line with the feet.

When walking, we change the base from one foot to another; this gives a swaying motion to the body: thus people cannot walk well together, when linked by their arms, without keeping in step, so that both bodies may have the same motion.

When carrying a burden on the back, we lean forward; if on the chest, we lean backward; if on either shoulder, we lean to the opposite side.

In that useful domestic utensil, a pail (fig. 9), the centre of gravity is near to the centre; and the handle, which is the centre of suspension, being fixed vertically over it, the centre of gravity must ascend; this therefore keeps the contents safely within the vessel. In some measures, such as those used for coals, which are heavy and have to be frequently emptied, the handle is placed lower; thus little power is required to upset it, and empty the contents out quickly.

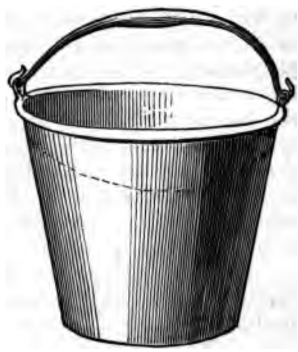


fig. 9.

In some instances the centre of gravity is not in the object itself; in a ring, it is in the middle of the space measured from every part of the solid circle.

If we take a circular piece of wood, and, near the edge, drill a hole and place a piece of wire through it, the wood will steadily hang from this axis; by making the hole exactly in the centre, the point of support will then be the centre of gravity, and the wood may be placed at rest in any position; but if the hole be made below this central one, then it is most unstable, and the least motion will cause it to reverse its position, as the centre of gravity will endeavour to get below the point of suspension. Thus, when the point of suspension is far above the centre of gravity, its steadiness offers much resistance to a disturbance from its balance. In constructing fine balances, by making the point of suspension just below the centre of gravity, the balance is delicate and easily moved, which gives value to the instrument.

In many mechanical contrivances, as well as in the experiments of science, the position of the centre of gravity is an important fact to ascertain. If a rod of iron be five feet long and equally made, the centre of gravity will be exactly in the middle of the length; but if a weight of one pound be fixed on one end, and a weight of four pounds on the other

end, then the centre of gravity will be at one foot distance from the four-pound weight, the other weight and four feet of the rod being required to counterbalance the opposite; thus the length of rod at each side from the point of suspension is in exact opposite proportion to the weights—that is, as one is to four. The point thus found is also called the *centre of inertia*, and is the *centre of centrifugal force* as well; for were a twirling body not to have its axis made in that part, one portion of the hole in the wheel would wear out much quicker than another.

Were a small ball attached to a larger one by a chain and fired out of a cannon, the two balls would be seen to fly round and round each other, and the centre of gravity would not be in either ball, but according to their proportion nearer to the large one, and this part in their motion would describe a curve.

The sun and the earth are bound to each other by attraction, and have a centre of gravity. In so speaking, we are not now describing atoms of matter, but masses. Say, then, the earth to be 1, then the sun is 354,936; and the centre of gravity of the sun will be 270 miles from its centre, which is the $\frac{1}{3300}$ part of its diameter.

The earth and the moon, by the attraction of the sun, revolve around it, and are as one mass of matter to that great body. Saying that the earth is a large ball and the moon a small one, they are held together by attraction, as if by a bar of iron; and thus they form a joint system, having a common centre of gravity. The moon is in bulk but the 49th part of the size of the earth, while from its density it is not more than the 70th of its mass; thus the mutual centre of gravity which will mark the line of the motion of the two bodies is a little below the earth's surface; and if the earth were drawn to the sun, this would be the part that would be attracted most strongly, and is that which describes the oval motion around the sun.

Animals, from the broad base they have to support their weight, are enabled to walk sooner than man. A horse, when moving, first lifts up a hind-leg, leans its body forward, and then lifts up the fore-leg on the same side as the hind-leg it first moved; thus the centre of gravity is advanced: the other hind-leg is next moved, then the fore one on the same side, progressing in this way onward. In trotting he lifts and puts down two feet at once, those diagonally opposite. In galloping he lifts and sets his feet down one by one, though the two fore and hind feet are set down nearly at the same time. Animals with many legs lift the hind one first, and all at one side before moving those on the other side. Thus the centre of gravity is moved in a swaying manner.

CHAPTER II.

SIMPLE MACHINES.

A SIMPLE machine is an instrument by which weights can be raised, the resistance of heavy bodies overcome, and motion communicated to masses of matter. It is by the application of *simple machines*, or *mechanical powers*, that man accomplishes many useful undertakings, which, without such contrivances of his ingenuity, would be beyond his natural strength.

Complex machines may be traced to be merely peculiar arrangements of simple mechanical powers.

The natural forces or powers at the command of man for producing motion are few, being principally the strength of men and horses, running water, steam, fire, and wind.

It is the ability to regulate, accumulate, and divide the speed of power, and to connect, oppose, and counterbalance different velocities, that gives the great value of mechanical power to man. Machines do not beget or increase force; they only apply that which has been communicated to them in an advantageous, easy manner.

The power applied must be greater than the resistance, otherwise there would be no motion.

In the volume on *Natural Philosophy*, it is stated that the velocity of a body is measured by the space passed over in a given time.

If we notice the wands of a windmill in rapid motion, the outer parts can hardly be seen, while the parts nearer to the centre of motion can be easily distinguished. Now, both parts take the same *time* to perform their journey round; but from the greater space passed over by the ends in the same time, the velocity is proportionally increased (fig. 10).

fig. 10.

In some collieries there is a large wheel used to draw the coals to the surface, and underneath the wheel there are yoked two horses, one outside and underneath the wheel the other further in; and it will be observed the outer horse has to keep

walking at a very brisk pace, while the inner one moves in the most deliberate manner possible (fig. 11). The relative length of the arrows in the annexed diagram shows that of the speed of the horses (fig. 12).

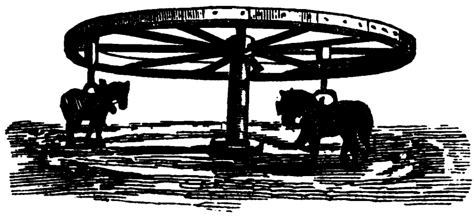


fig. 11.

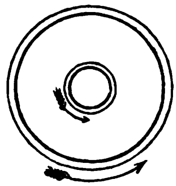


fig. 12.

See, again, those youthful aspirants at our fairs for a ride on a roundabout, who get between the poles to push it along, giving this labour to purchase the luxury. Those near to the happy customers have to run with all their might, while those near to the axis move at almost a walking pace.

There is a contrivance for drawing water used by the market-gardeners near London, that will also serve to illustrate the present subject. We cannot here resist remarking the amusement we lately felt on reading a traveller's grave and minute description of this ancient practice as a piece of clever simple mechanical contrivance which he had discovered on his foreign travel. It is too much the case, that people pass through their own country with their eyes half closed, and only open them wide when a thing is of foreign produce.

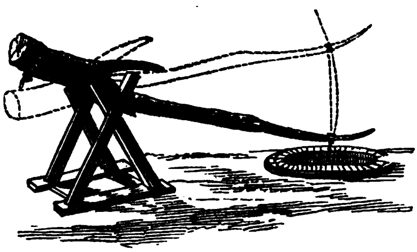


fig. 13.

Suppose a man to pull down the large end of the pole, fig. 13, at the same time the other end moves through twice the space, consequently with twice the velocity, while both ends describe in their motion a part of a circle. By having the end of the tree heavy some power is gained.

Time is exchanged for *power;* or, as it is sometimes expressed, "What we gain in power we lose in time or speed." This is termed the law of virtual velocities, or the golden rule of mechanics. Thus, if a person could raise 50lbs. to a certain height in one minute, and by the help of machinery he raises 500lbs. to the same height, it will be found that the time occupied in lifting up the 500lbs. would be ten minutes: thus the tenfold increased power has to have a tenfold increased time, or the work of ten minutes could have been accomplished in ten different efforts in the same time.

The primary mechanical powers are the *Lever*, the *Pulley*, and the *Inclined Plane.* The *Wheel and Axle* are derived from the lever; the *Wedge and Screw* from the inclined plane.

THE LEVER.

Of all the mechanical powers, the lever is the most simple. It is formed of any strong substance, in the shape of a beam or rod, which rests on a prop or axis called a fulcrum, which is its centre of motion. There are three kinds of levers. The following is an exemplification of the *first* (fig. 14):—

In this diagram, *l* is the lever, *f* the fulcrum, *w* the weight. By pressing down at the end *l*, the other end of the lever raises *w*, the weight; the centre of motion is at *f*, the fulcrum. In other words, the power or force resting on the prop or fulcrum overcomes the weight or resistance. Thus, if the end of the lever be under the centre of gravity of the weight, and the length of the lever from the fulcrum be twice as long as the other part, a man can raise the weight one inch for every two inches he depresses the end of the outer extremity of the lever.

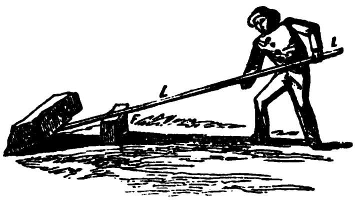


fig. 14.

Now, if the end of the lever be four times the length of the part from the fulcrum to the centre of gravity of the weight, then the power of raising the weight is increased four times; but the space that the *l* end of the lever will pass through is four times greater.

It will thus be perceived, that if a weight of one stone moves through a space of ten feet, we may raise a weight of ten stones through a space of one foot; or a weight of ten stones moving through a space of one foot will make a weight of one stone move through a space of ten feet.

Now, if a man can raise the weight at the end of the lever, and then the lever be made twice as long, and a boy of half the man's strength can then raise it, the boy will be sooner worn out by fatigue than the man, because the man in the exertion of his strength only goes through half the space that the boy has to pass through. It is stated that "The force of the lever increases in proportion as the distance of the power from the fulcrum increases, and diminishes in proportion as the distance of the weight from the fulcrum increases." It was from this general law that Archimedes exclaimed, "Give me a lever long enough, and a prop strong enough, and with my own weight I will move the world." This was true; but, from the immense parts of a circle his lever would have had to describe, if at the rate of 10,000 feet an hour for about eight hours a day, it would have taken him nearly nine billions of centuries to raise the earth an inch.

If a lever, either formed as a scale-beam or having a fulcrum underneath, have a length from the fulcrum of six inches, and a weight upon it of 100lbs., and it be desired to know what length of lever would counterbalance this, multiply the weight by the distance from the fulcrum, when the result will be 600; calculate the weight, 100lbs., as inches, and make the other end of the lever this length, having upon it 6lbs. weight—for 6lbs. multiplied by 100 inches is equal to the other result, 600, the weight and power balancing.

Should it be desired to know what power will balance a certain weight at the short end of the lever, it is done by multiplying the weight by the length of lever from it to the fulcrum, and then dividing the result by the other length of lever, and the result is the power required. Thus, if 100 lbs. be on one end of a lever 12 inches from the fulcrum, $100 \times 12 = 1200$; then, suppose the long end of the lever be 24 inches, $1200 \div 24 = 50$ lbs., the power required.

A *spade* is a lever, the earth being a fulcrum, in the operation of digging. In Ireland they make it a long lever in comparison to that used in England; and thus a man stands upright when digging, with the tails of his greatcoat tucked up behind him. The fisher-girls who dig for worms as bait in the sands on our coast also use a long-handled spade; this is to compensate for manual strength.

In moving barrels and very large weights, and principally on board of ships, a *hand-spike* is the lever found best adapted to the purposes required.

Carpenters, masons, and others, who have to move bulky masses of matter short distances, adopt the use of a *crowbar*, which is a lever made of iron, having a claw at one end.

A hammer has usually a claw for drawing out nails; now in this the power seems great, for the nail will bear an immense weight attached to it; yet, because we move the hand through several inches while the nail moves only a very short way, we can draw it out, and thus the velocity overcomes the resistance.

The *fire-poker* is a lever, having the bar of the grate for a fulcrum.

The simple lever has sometimes two arms; it is then called a double lever. *Scissors* are of this kind, having the rivet as a fulcrum for both. Large scissors called *shears*, used in cutting cloth, pasteboard, tin, copper, and sheets of iron, are double levers.

Nippers, pincers, forceps, snuffers, are all of this description of levers.

The *scale-beam* used in weighing is a simple lever. The arms, *a a*, fig. 15, on each side are made of equal length, and suspended over the centre of gravity. The axis or pivot *b*, which is the point of suspension, is sharpened to a very thin edge, sometimes equal to that of a razor, that the beam may easily turn with as little friction as possible when weights are applied in the scales. Should the arms not be of equal length, then the scales cannot act justly, although the beam may seem fairly balanced and the weights true; but if one was half an inch longer than another in an arm of eight inches in length, the customer would lose an

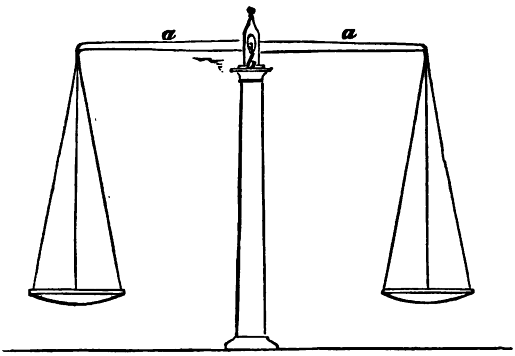


fig. 15.

ounce in every pound. The deceit can be discovered by changing the weight and material to the opposite scales.

In some cases where the beams of scales are not accurate, the articles to be weighed are put in and balanced by shot, sand, or other things; the things of which it is desired to know the weight are then removed, and weights put in their place—thus the true and exact weight is known. By this mode almost any elastic substance may answer the purpose of a weighing-beam. Suppose a piece of steel, or a walking stick that will bend, were held over a place, and a substance attached to its end; then, when so attached, mark exactly the place the stick or steel bent to when the substance was on it; remove the thing to be weighed, and attach weights until the steel or stick bends again to the mark, and then the weight of the material is truly found.

The Chinese and Romans use, instead of the weighing-beam, an instrument called a *steel-yard* (fig. 16), which is a lever with arms of unequal length. The lever is suspended from a hook *a*, which is the fulcrum or pivot, and from which the steel-yard must truly balance: this is its centre of gravity. Thus, one pound weight will weigh any number of pounds in the scale that the yard is long enough to perform. In the diagram, the one pound weight at *c* is weighing eight pounds in the scale at *b*, for the space over which it is placed on the long arm of the lever is eight times that where the scale hangs from on the short arm. By dividing the spaces in the long arm into halves, quarters, and sixteenths, then half-pounds, quarters, and ounces can be weighed. In applying the rule for calculation previously given to the steel-yard, it will be found as stated: thus, the short arm is 1, and the weight or resistance in the scale is 8, then 8 multiplied by 1 is equal to 8; the length of the long lever from the fulcrum is 8, and the weight 1; 8 multiplied by 1 is equal to 8, thus both are in equilibrium.

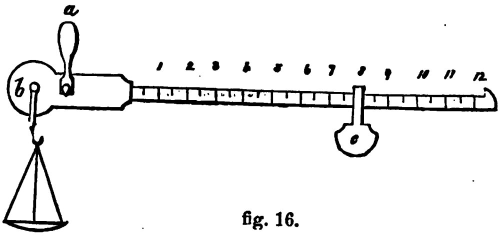


fig. 16.

We may here notice the Danish balance, which is a modification of the steel-yard (fig. 16[a]). In this construction the weight *a* is permanently at one end, the article to be weighed suspended from a hook at the other end; while the handle for supporting the balance, and which forms the fulcrum, is placed at a point somewhere between these. As may be noticed, the gradations are not at equal distances, as in the steel-yard. This is owing to the fact that the centre of gravity of the beam is constantly changing. Thus, suppose the centre of gravity is at *b*, and the fulcrum placed there, the beam will be perfectly balanced; but if a weight, or an article to be weighed, is placed at *c*, the centre of gravity will be shifted nearer to the weight, say to *d*; the fulcrum then must be moved to the same point. At each change, then, of the weight of the

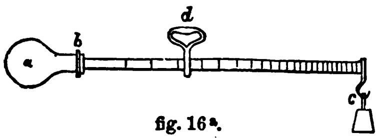


fig. 16[a].

article at c, the centre of gravity being moved and also the fulcrum, there is a difference made in the length of the respective levers; moreover, the weight of the portion of the lever from d to b is transferred from one side to the other. The best way to graduate this balance is to place certain definite weights on the hook c, and mark the place where the beam is balanced.

An equally-made spring is sometimes used as a measure of weight, from its compactness; the letter-balances, now so common, are a familiar example.

The annexed diagram (fig. 17) represents a spring balance: a cylindrical case b b, of iron has one end filled up by a tightly-screwed cover, to which the hook or ring a is fastened, by which the balance is suspended. The spring coils spirally round the spindle c c, which is securely fastened to a circular plate e e, which moves in the inside of the case b b somewhat like a piston. The lower end of the spindle c c has a hook, to which the dish d is suspended; or, instead of the dish, the article to be weighed may pass over the hook. On the hook being pulled downwards, the balance being suspended by a, the spindle also pulls the piston e e, and consequently depresses the spring in proportion to the force employed. The spindle is divided into graduated spaces near the extremity of the case at f; according as these are seen out of the case, so is the weight of the article indicated.

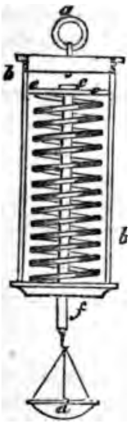


fig. 17.

The elastic force of a spring, not being affected by terrestrial gravitation, is that which is used to ascertain the amount of the earth's attraction in various places.

The spring has a weight attached to it, and is made to swing clear of the bottom of the machine; weights are then added until the weight just grazes the bottom of the stand. The machine is then carefully packed away, and removed to the place where required, and the difference of the weights there necessary is the difference of the gravity. This is a most delicate instrument, and, from its truthfulness of action in all latitudes, shows the difference of weight or heaviness in all parts of the earth's surface.

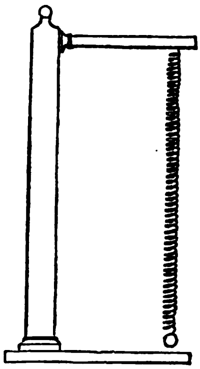


fig. 18.

The second kind of lever is that where the weight and the power are on the same side of the fulcrum, the weight being placed between the power and the fulcrum.

fig. 19.

Thus, if a mason (fig. 19) desires to move forward a large piece of stone, instead of bearing down upon the lever to raise it up a little, he sticks his crowbar into the ground, and pushing upward, moves the stone little by little onward, the ground being the fulcrum.

A wheel-barrow affords another example: in using it, a point in the

wheel of the barrow pressing on the ground is the fulcrum; the load is the weight, and the handles held by the man the power; as the person shortens or lengthens his hold on the handles, so does he move the centre of gravity to the wheel or himself.

If two men carry a load slung from a pole resting on their shoulders, and the load be in the middle between them, they have an equal share of the weight; but in proportion as it is more towards one than the other, so is the extra amount of weight to the one nearest to it. The men are the fulcra in this case; they act in that capacity the one to another, while both are the moving power. Should the pole be eight feet long, and the weight 200 lbs., placed in the centre, each man will bear 100 lbs. weight. Suppose that a man and a boy are set to carry this weight, and the man, from the boy's inability to carry his equal share, out of humanity places the weight four times as far from the boy—that is, about 6 ft. 4 in. distance, and only 1 ft. 8 in. from himself—then the boy will only have about 50 lbs. weight, while the man will have 150 lbs. to bear.

A hand-barrow is on the same principle; and one man may bear less or more as the load happens to be placed, or as the handles may be held to increase or lengthen the lever.

In yoking horses to a loaded wagon or coach having cross-bars, care is taken that the bar is hooked to the centre of the load. Sometimes a small, weak animal is placed to assist one larger and stronger; in that case, the cross-bar is not placed equally, but more past the centre for the bigger animal.

Thus, in dragging a plough by the chain *a* (fig. 19[a]) which is attached to the bridle, where the horses are of equal strength, the land side "swing-tree," or "whipple-tree" *e*, and the furrow swing-tree *f*, are attached by the chains to the main swing-tree *b c*, at points equidistant from the centre *d*, to which the chain *a* is attached. But where the one horse is much weaker than the other, its deficiency in power is com-

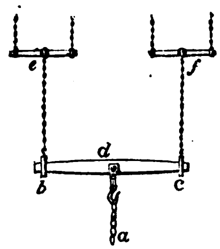


fig. 19[a].

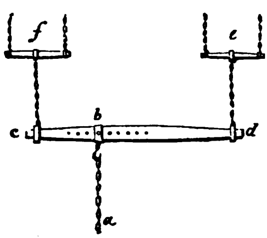


fig. 19[b].

pensated by yoking it to the whipple-tree *e*, which is attached to the long end of the main swing-tree *c d* (fig. 19[b]). The strongest horse is attached to the swing-tree *f*, connected with the short end *b c* of the tree *c d*. The point of attachment *b* of the chain *a* is capable of adjustment along the swing-tree *c d*, its pin being moved from hole to hole as required.

The common operation of opening a door is an illustration of this lever; the hinges are the fulcra or centres of motion, the door the resistance or weight, and the hand the moving power. The finger is painfully

nipped when caught near the hinge, from that part being near the fulcrum, acted upon by a lever passing through a larger space. In opening a box the same is noticed (fig. 20). Every one has experienced that on

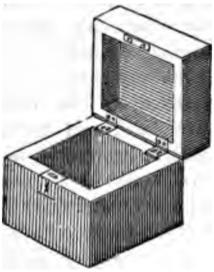


fig. 20.

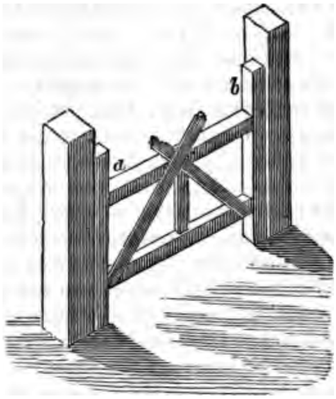


fig. 21.

opening a door or gate when near to the hinge *b* (fig. 21) the force required is considerable, having little space to pass through; whereas near to the latch *a* the task is easy, though the space is increased.

The oar of a boat is also a lever of this kind; the water being the fulcrum, the person who rows, the power, and the boat the resistance or weight. This lever is most powerfully employed in the coal-barges on the rivers in the north of England. These vessels retain the old Saxon name of *keels*, which is the term that distinguished the ships containing Horsa and Hengist and their enterprising followers on first coming to this country. They are in the form of half a walnut-shell, huge and unwieldy, and contain upwards of twenty-one tons of coals. The keel is propelled with one immense oar, wielded by three men remarkable for their muscular powers; they pull with all their might, adding the entire weight of their bodies, as they do not sit, but move backward with the motion of the oar: thus this heavy, clumsy barge has but the yielding water for a fulcrum, and yet is skilfully managed even among the waves of the ocean.

The *masts of a ship* act as levers, having the cargo or ballast and the vessel as the resistance, the bottom of the vessel as the fulcrum, and the sails holding the wind as the moving power. Thus we see in well-equipped smuggling-vessels and gentlemen's yachts, where the masts seem enormously high for the size of the vessel, that they lean over when in full sail, by pressure on the levers, in a fearful manner.

Nut-crackers, *lemon-squeezers*, &c., are illustrations of this kind of lever. The two legs are joined by a hinge, which is the fulcrum; the article placed between is the resistance; and the hand is the power.

The *rudders* of boats, ships, &c., are levers acting on the same principle.

Many are the industrial purposes to which this form of the lever is applied by chemists, grocers, chaff-cutters, coopers, patten-makers, &c. &c.

The wooden soles of the shoe called a *clog*, at one time almost universally worn by boys and countrymen, was formed by this cutting lever. In snowy or wet weather, or where persons' avocations compel them to work amid wet or stand on cold stones, this ancient shoe is invaluable in the preservation of health, being warm and dry. In the college at Manchester we have seen this cutting lever (fig. 22) used in cutting bread; and so excellently was the work performed, that all the fragile delicacy of a "Vauxhall slice" was gained with a rapidity and regularity that would have caused envy in the bosom of the lessees of that place, so notorious for its transparent dainties.

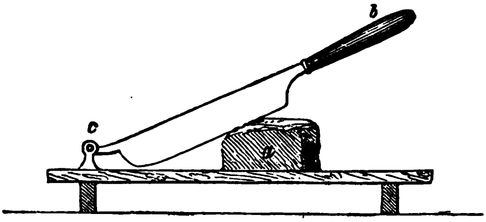


fig. 22.

This lever is a common appliance in the country for bending down haystacks partially cut, and other loose light bodies that might be carried away by the wind; and it is even retained in some places for pressing cheese when in course of manufacture. A pole is stuck into a wall as a fulcrum, the resistance is the object to be pressed or held in its place, and at the other end are hung weights as the power (see fig. 200).

The *third* description of lever is that in which the fulcrum is at one end, the weight at the other, and the power placed between them. At one time this was called the *losing lever*, because the power had to be greater than the weight. The advantage of it is now discovered and appreciated, consisting, as it does, in a small power causing the extreme point of a long arm to move over a great space; and is one of those wonderful adaptations of the Divine Being in the construction of the appropriate mechanism of animals and man. A man raising a ladder, as in fig. 23, illustrates this form of lever.

fig. 23.

The domestic implements *fire-tongs* have two long levers with a small motion near the pivot, near which the power is applied: thus they open widely to grasp a large coal or cinder, and have a weak power at the ends, but powerful near the fulcrum.

The mechanical power of the muscles of man, acting on the bones as levers, is one of a surprising nature in the combination of power, velocity, and beauty of construction. The arm (fig. 24) will be a sufficient illustration. The elbow is the fulcrum, the muscles the moving power, and the weight raised the resistance. Thus if the weight

fig. 24.

raised be 50 lbs., and the elbow passes through a space of 20 inches, the muscles springing from the shoulder will contract 1 inch, and the force be equal to 1000 lbs. The muscles being near the joints or fulcra, give a high degree of velocity to the other end of the lever, generating great momentum. In the human body sometimes the fulcrum is between the power and resistance, as the elbow between the muscles of the shoulder and humerus, and the hand with the weight; in other places the resistance is intermediate, and the fulcrum at the end, as the toes on the floor and the hinge of the lower jaw; and in parts the fulcrum is at the end and the power intermediate, as the weight of the arm has its fulcrum in the shoulder-bone, and the power is in the muscle covering and proceeding from the shoulder.

The muscles of large emigrating birds must also be most powerful, sustaining the weight of their bodies while they travel unrested for days amid the tempests of the heavens.

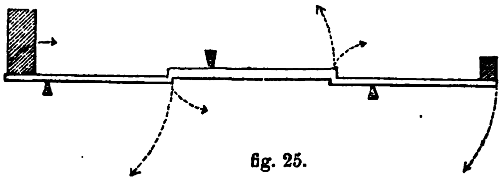


fig. 25.

Compound Levers are arrangements of simple levers by which less space is required, thus: suppose (fig. 25) three pieces of iron 12 inches long, having their fulcra placed 3 inches from the ends of each, let us see what 1 stone (14 lbs.) moving power placed at the end of the first will balance at the end of the last: 9 inches to the fulcrum of the first lever multiplied by 1 stone is equal to 9, then the 3 inches at the other side of the fulcrum divided into 9 gives 3 stone as the balance at its end. Three stone, then, is the power at the commencement of the second lever, which must be multiplied by its 9 inches, giving as a result 27; this divided by the 3 inches at the other side of its fulcrum makes 9 stone as the power at the beginning of the third lever, which multiplied by its 9 inches results in 81, which divided by the 3 inches at the end, the total weight of the block at the other end is found to be 27 stone.

It is by this kind of combination that at railway stations luggage is weighed; and at entrances to towns where tolls are paid according to weight, carts and wagons are drawn on to tables and their heaviness known. By lengthening the arms on one side of the fulcrum and shortening them on the other, the force is greatly increased.

Bent Levers.—The levers we have considered are supposed to act at right angles, and the power may be the less the farther it is from the fulcrum. Bent levers are often used for their aptitude to peculiar circumstances, and act obliquely, consequently, with less effect.

A bent lever balance will show the principle (fig. 26). Now, the end of the long arm where the scale is attached does not act upon the entire length of lever, that is to the weight, but only as far as the fulcrum at the top of the stand, while that portion with the weight upon it acts as if it were not longer than the fulcrum; therefore, a weight of two pounds on the short arm will balance a weight of one in the scale. Thus, as the long and short arm move out of the imaginary dotted line, so is the influence of weight.

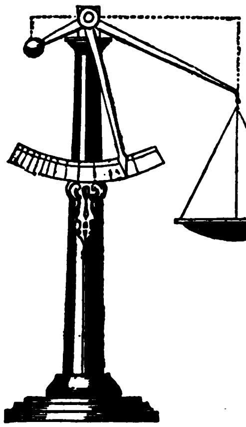


fig. 26.

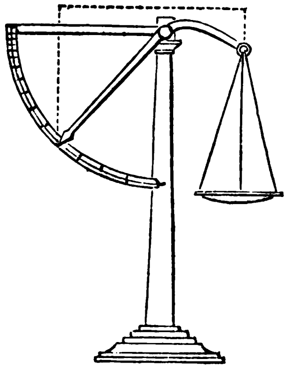


fig. 26ª.

The method of obtaining the imaginary lever from whieh to calculate the power of a bent lever, is thus illustrated : Let *b e c* (fig. 26ᵇ) be the

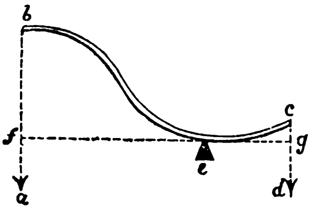


fig. 26ᵇ.

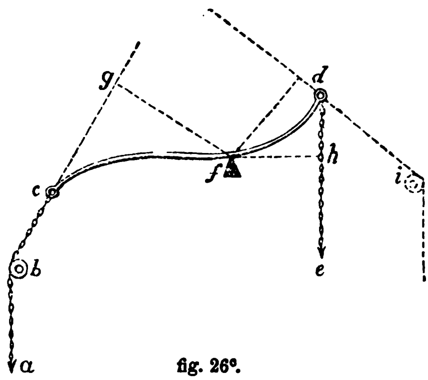


fig. 26ᶜ.

bent lever, *b a* the direction in which the power *a* acts, *c d* that in which the weight is lifted. At right angles to the line *b a*, from the point *e* of the fulcrum, draw a line *e f*, and from same point at right angles to *c d* —*f e* is the long, *e g* the short arm of the lever. In fig. 26ᶜ, the power *a* is acting on the lever *c d* over the pulley *b* in the direction of *b c*, the weight *e* in the direction of *e d*. Produce the line *b c* to *g*, from the point *f* draw a line at right angles to *b g*, cutting *b g* in *g*, from *f d* at right angles to *d e* draw a line *f h*, cutting *d e* in *h*; *g f* is the long, *f h* the short arm of the lever. But, suppose the weight *e* to act on the lever in the direction *i d*, produce *i d*, and from *f*, at right angles to *d i*, draw a line cutting *d i* in *d*; then *f d* is the short arm of the lever.

Fig. 26ª is another form of the bent lever balance. The fulcra of levers, as those in balance-beams, are of a triangular shape, as in fig. 25. The fulcra of levers, however, as used in machinery, are cylindrical, supported in the interior of a cylindrical aperture made in the material

in which the lever works. To reduce the friction, brasses are inserted, in which the lever works. The fulcra thus constructed become available not only where an oscillating or vibrating action is given to the lever, but where the motion is circular, the fulcrum in this case becoming the axis of rotation, as in

THE WHEEL AND AXLE.

This simple machine consists of a wheel W fixed upon an axle A. Suppose it took 1 foot of rope to go round the axle, and 4 feet to go round the wheel, then the proportion would be as 1 to 4, and a weight of 1 lb. at the wheel would support a weight of 4 lbs. at the axle. If the rope be wound round the axle in a different direction to that on the wheel, and an increase of weight be attached to the rope at W, then it would unwind and the weight descend, while the rope on the axle would wind up and lift the weight fastened to it. Thus one power is made to act against another, as pointed out in the lever.

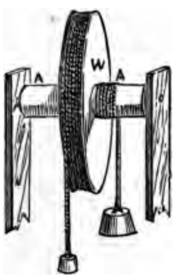


fig. 27.

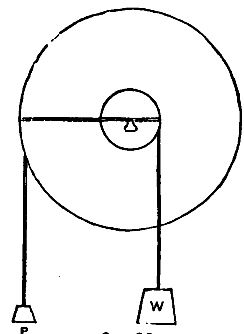


fig. 28.

The wheel and axle are called a perpetual lever. In the diagram, fig. 28, it will be seen how the term may properly be applied. The power P is the weight hanging from the wheel, the fulcrum is the centre of the axle, and the weight to be raised that hanging from the axle. Now, if the distance from the edge of the wheel to the centre of the axle be 8 inches, and from the centre to the edge of the axle be 1 inch, and 1 lb. be the power hanging from the wheel, it will balance 8 lbs. hanging from the axle. A slight addition of power, then, would raise up the 8 lb. weight; but for every inch the weight rises, the power would descend through 8 inches of space. The dotted line shows that a handle inserted would act the same as a wheel. As must be evident, a lever would only raise the weight through a small space, while the wheel and axle will act as long as the length of the rope will allow.

The larger the wheel and the smaller the axle, the more powerful is the machine, but the greater time is taken in raising the weight.

In the *gin* used at collieries of small depth, in threshing-machines, and plaster mills, and various other useful occupations of commercial industry, the principle is of infinite service.

In the common method of drawing water from a well, the handle is made to describe a large circle, and thus performs the part of the wheel

described, while the axle receives the rope with the weight. When the well is very deep, and the rope overlaps several times on the axle, then the operator finds, as the bucket approaches the top, that more and more power has to be applied: the cause of this is, that the rope winding upon itself increases the circle on the axle, while the handle describes the same motion through space; and as a larger axle requires more power, the weight feels augmenting.

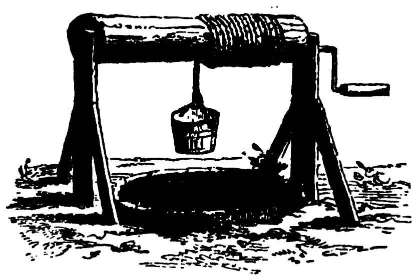


fig. 29.

That punishment accorded to petty offenders, *the treadmill*, is a large wheel having the outer parts arranged so that the condemned turn it round by lifting their feet as if stepping up stairs, which, by the weight of their bodies, pass from under them: the axle of the wheel is connected with apparatus for grinding sand or other things. Cranes at one time were worked on this plan, but the men were inside the wheel instead of outside: the clumsy contrivance has given way to other more compact inventions. Some bird, mice, and squirrel cages are formed in the same manner.

The *windlass* used on board of ships for raising the heavy anchors,

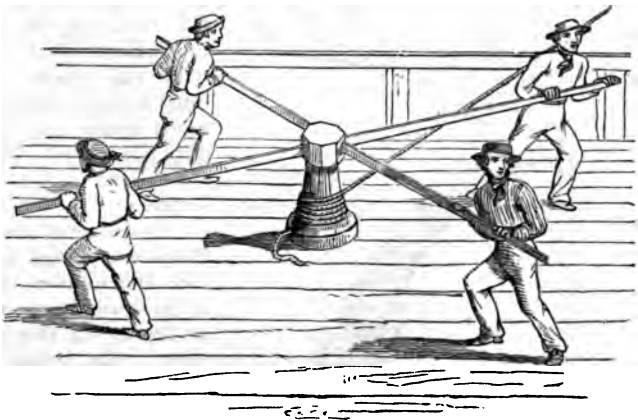


fig. 30.

and the *capstan*, are wheels and axles, the latter being upright. The head or drum has holes in it, in which are placed levers, or, as called, capstan-bars, against which the men push. They may be likened to the spokes of a wheel, but made movable; this causes the size of the wheel to be considerably enlarged, describing a large circle. If a capstan-bar be six times as long as from the edge to the centre of the part on which the rope is coiled, and six men are at six bars, they will raise thirty-six times as much weight as one man could do by his unassisted strength. Capstans are used to open and shut dock and canal gates, drawbridges, &c.

The handle applied to a coffee-mill, a draw-well, a crane, or a grind-

stone, may properly be called a *winch*. In fact, wherever a circle is described by the hand, it is of little consequence whether there be one or more spokes or handles, the principle is the same.

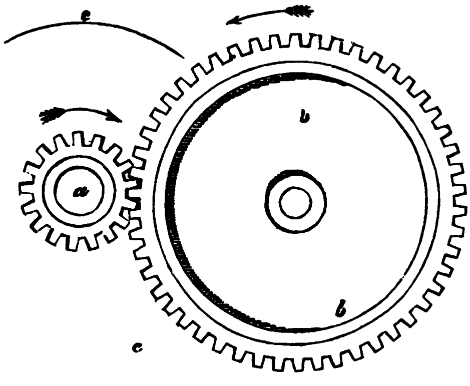


fig. 31.

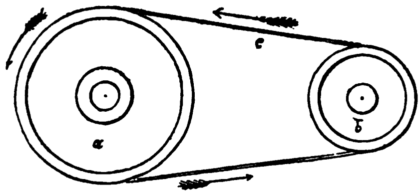


fig. 32.

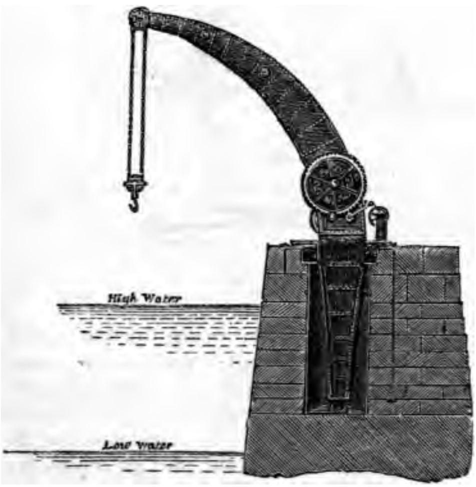


fig. 33.

If two large wheels be notched or toothed so as to fit into each other, they revolve in the same time, and a weight would be raised by the axle of one as soon as the other. Where different velocities are required, and machines are to be of compact formation, then a combination of wheels is made by introducing what is called a pinion.

In fig. 31 let *b* represent a wheel, and *a* the axle of another. It will be seen that the teeth placed round the edge of the one wheel work in the teeth placed round the axle of the other; thus then, as the wheel with the teeth at its edge is much larger than the axle with the other teeth, it must consequently go round much slower than the axle or pinion-wheel. The teeth on the axle are termed leaves.

The mode of calculating the power gained is to divide the number of teeth in the wheel by the number of leaves in the pinion; thus if the latter has 12 and the former 144, then $144 \div 12 = 12$, the power gained; which may be either velocity or intensity between weights or forces.

In lathes, spinning-wheels, printing-machines, &c., wheels without teeth are made to act upon each other by means of cords, straps, or bands; this adds *nothing to* the power, but is useful in the regulation of a quick or slow *motion. Thus in fig. 32* the wheel *a* drives *b* by the belt *c*.

By increasing the number of wheels working into each other, or by proportioning the wheels to the axles, any degree of power may be acquired. On this principle cranes (fig. 33) are made, by which a man can raise many tons. The pulley over which the rope or chain is passed at the highest part is to change the direction of the draught; and the weight may be raised to the height required by a person standing on the same level with it. As it swings on a pivot, the packages are moved, when hoisted up, to the parts required, within reach of the crane.

THE PULLEY.

This simple machine is a small grooved wheel, called a *sheave*, made of hard wood, with a rope passing over it, fixed in a scooped-out *block* of wood, moving round a pin passing through its centre. Sometimes they are made of brass, iron, and china-clay.

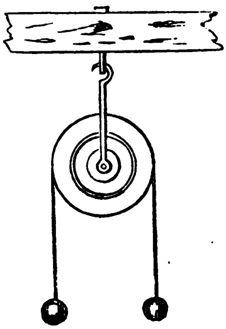


fig. 34.

fig. 35.

A *fixed* pulley (fig. 34) with two equal weights at the ends of the rope passing over it, gives no mechanical advantage, for the weights balance; and when moved, they rise or fall through an equal space in the same time. The service to which it is applied is merely to change the direction of the power, and enables a man to stand on one spot and raise a weight which he might otherwise have to carry up a ladder (fig. 35). Another use is that of enabling several men to join their strength at one time in raising a considerable weight.

The pulley forms one of the most valuable assistants to the toiling and hardy sailor, and by its means fewer men are required to do the necessary work of the ship. It is hung about all parts of the rigging, and is ever a ready helpmate; by its means, amid calms or storms, the weather-exposed mariners can stand on the decks of their vessels and hoist the booms, spars, and sails of the loftiest vessel that the ocean bears on its bosom.

A man, by placing himself in a loop of a rope passed over a fixed pulley (fig. 36) may by his own strength raise himself up or lower himself

down as he pleases. This is sometimes practised by workmen when a slight repair has to be done to the front of large mansions: for safety, one end of the rope is fastened round the body; if movable blocks be added, the ascent and descent are very easy. The reason of this being accomplished with a fixed pulley is, because the man throws more than half his weight by his strength on one side of the pulley, which causes that side to descend, while the other part with the loop in which he sits rises.

fig. 36.

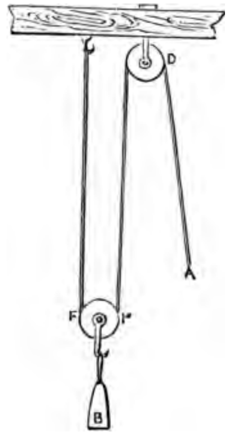


fig. 37.

A *movable* pulley F (fig. 37) is sometimes fixed to the weight B, which has to be lifted, and rises and falls with it; the rope passes under it, having the pulley hanging upon it. It is plain that the weight must be equally borne by both sides of the rope, the one end fixed in the hook, and the other held by a man at A: as to its passing over the fixed pulley at D, that is only of use as a convenience in giving direction to the rope. Then between the hook and the man there must be action and reaction, which being equal and contrary, the weight becomes divided. If the weight were 8 stone, the man has only to bear 4; still he must draw up 2 feet of rope, that is, 1 on each side of the pulley, to raise the weight 1 foot: hence it is very evident that in doing so he lifts 4 stone 2 feet; that is, though the weight has passed through only 1 foot, yet he has pulled the rope 2 feet. But then the weight he pulled at during the time was only 4 stone; without the pulley he would have had 8 stone to raise 1 foot; thus the weight was one-half, but the space he pulled through double to the movement of the weight.

To increase the advantages of the pulley, several are combined together. In fig. 38 there are two fixed pulleys and two movable ones; thus the rope, it will be observed, passes four times over them, and the resistance capable of being overcome is as 4 to 1: that is, if a power of 100 lbs. was applied, it would be equal to a weight of 400 lbs. to be raised. Each fold of the rope bears a fourth of the weight, the last being the power applied; that over the top fixed pulley is of no more use than to aid the person pulling the rope in giving it a proper direction.

Thus, then, an increase of pulleys decreases the weight, and allows a

smaller power to overcome a larger; still it is always at a loss of time and space.

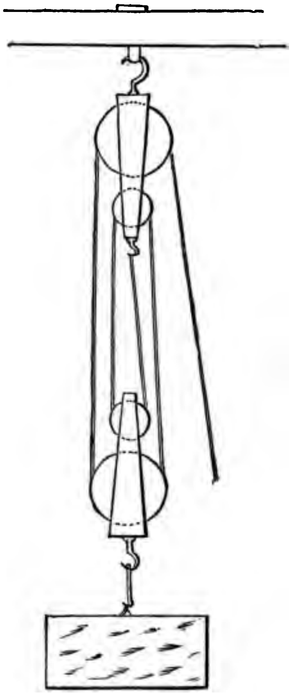


fig. 38.

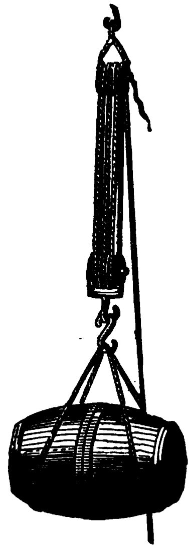


fig. 39.

The ropes used about a pulley are called tackle, and the pulleys blocks; therefore, when a sailor or workman collects together all necessary for the application of this machine, he speaks of the *block and tackle.*

The placing a number of pulleys together in many cases would occupy too much space, besides other inconveniences. To avoid this, and at the same time reap advantage, it is common to have several pulleys in one block on the same pin, fig. 39; thus there are sometimes two, three, four, or more sheaves placed side by side, having a strong pin as an axis driven through the whole: by this means the power can move the resistance two, three, or fourfold, as in the rules already given. In a three-sheaved movable block 100 pounds would balance 600 pounds, and so forth.

Sometimes a wheel and axle is employed to wind up the rope attached to a block and tackle; this combines the power of the lever with that of the pulley.

THE INCLINED PLANE.

This is another of the primary mechanical powers, and is of use to man in many of his daily occupations of raising or lowering weights short distances, as it gives to a small power facility in overcoming a larger.

If a cask be on a flat surface or plane, it will be at rest on any part of it where it may be laid; but, had a man to lift it on to a cart (fig. 40) he would have to apply a power equal to its weight to prevent its falling upon the ground. Were he, however, to place a plank up to the bottom of the cart, he then makes an inclined plane, and he would only have a

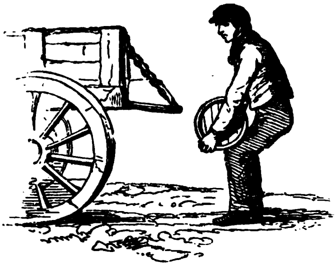


fig. 40.

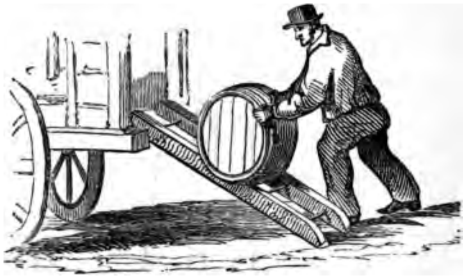


fig. 41.

part of the weight of the cask then to support (fig. 41). Or had the man to load the cart with casks, he might have to lift them from the ground perhaps four feet; but by placing a plank eight feet long, and forming an inclined plane, he can roll them up with one-half the power he would have to exert when lifting them, yet he would be double the time, as the space would be twice that of the height. An inclined plane, then, is seen to be a slope, and according to its height will the time be of a body in rolling down it; thus, if it be 16 feet high at one end, and its length 32 feet, a cannon-ball or cylinder will, by the force of gravity, fall through the 16 feet in 1 second, but to roll down the incline it would take 2 seconds; if it were 64 feet high, and the inclined plane 3 times 64, or 192 feet long, then a ball would fall through the space or height in 2 seconds, but would take 3 times 2, or 6 seconds, to roll down the incline.

Thus this mechanical power is in proportion as the length of the plane exceeds its height; and if a cask weighing 3 cwt. had to be rolled into a cart or part of a warehouse 4 feet high, and a plank 12 feet long was used, then a power of 1 cwt. would balance it, because the inclined plane is three times the perpendicular height. A slight power over the hundred-weight would move the cask onward.

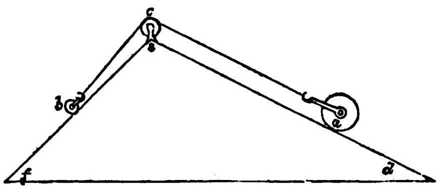


fig. 42.

If an inclined plane *d e* (fig. 42) be 4 feet long, and have on it a weight *a* of 12 pounds, to which a cord is fastened, passing over a pulley *c* to an inclined plane *e f*, 2 feet long, both having the same height, then a weight *b* of 6 lbs. on the short incline *will balance* the other, *a*, of 12 lbs.

If a loaded cart, omnibus, or coach, on a plane at the bottom of a *hill, had a plummet-line* hung from the top, it would fall straight to the

ground; but as the vehicle moved up the hill, the steeper it became the more the plummet would fall towards the back of the conveyance, and the heavier the load would become to the horse, increasing the difficulty to the animal in dragging it up the hill.

If the rise be 1 foot in 20 on a road, the horse has to lift the 1-20th of the load, as well as to overcome the friction and gravity; because in 20 feet the load has to be raised up a height of 1 foot, and the weight to be overcome at any part of the 20 feet is the 20th of what it would be if raised that height at once, being gradually lifted, as it were, the 20th part at a time over the 20 feet. The greater or less the slope, the greater or less power is required to overcome the resistance. It is this reason that causes drivers, on ascending steep hills, to wind from side to side, by which the incline is made less.

On railways, a locomotive engine can draw a train and 700 persons 22 miles an hour up an incline of 3 inches in every 8 feet; but were the incline 1 foot in 12 feet of length, then the engine could not move forward.

In the coal districts the inclined plane is of common occurrence on the railways. It is a curious sight to see twenty loaded wagons set off from the top of a hill, rushing down towards a river, without anything but a rope attached to the last one; this rope is attached to a small wheel or drum, and while the loaded wagons descend by their weight and velocity, empty ones, on a parallel line, are drawn upwards. As this is frequently a considerable distance, and as there are often curves in the road, the wagons seem moving uncontrolled downhill, and running unpropelled uphill. It is usual to make the railroads, or tramways as they are called, belonging to collieries on an incline; for by so doing, one horse can with ease move an immense weight of coal away from the mine to the place of sale.

In building houses an inclined plane is often used for the easy transit of wheelbarrows; and it is believed that the ancients, in erecting their immense works of art, used inclines formed of mounds of earth.

A curious illustration of the inclined plane and pulley was shown at the excavations of the Southampton and Sunderland Docks. A steep incline of planks (fig. 43) was laid down to the deep hole below, and a man hooking a rope on to a full barrow, which rope, passing over and under fixed pulleys, was attached to a horse, the animal received a stroke of a whip, walked sharply on, and the barrow, with the man taking long quick steps, leaning *far out of balance*, were as quickly at the top as if the horse had walked *up the incline.*

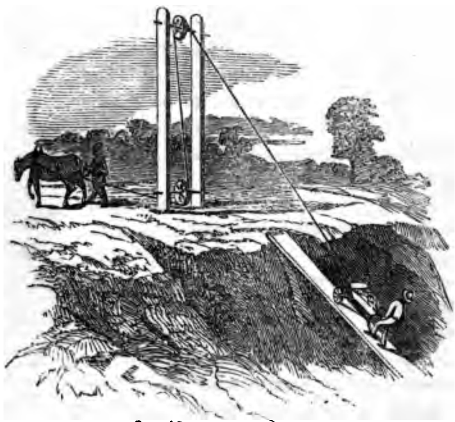


fig. 43.

The inclined plane is beautifully illustrated in that exciting and pleasing sight, the launch of a ship. Whether the destiny of the splendid triumph of man's handicraft be war or commerce, still it strikes with awe, wonder, and gratification, to see it move majestically down the sloped ways, breast all opposition, and then settle buoyantly and calmly on the surface of the waters.

To the drayman, in unloading ponderous hogsheads, the inclined plane is of great use; and again, when he drags the empty butts from the cellar, he places down a plank or two, puts a hook into the bung-hole at the end, fixes a rope to one of his horses, which he drives on, and thus drags up the barrel.

The stairs of a dwelling-house are an inclined plane in principle, having steps to allow of a footing. This forcibly struck us once on seeing a Highlandman who had never been in any other habitation than a cabin. He mounted the stairs well enough; but when about to return, after looking at them for a moment, he sat down, and descended as we would a steep declivity having foot-holds cut in it.

When roads are made to the tops of high hills, they are either wound round and round, or made so broad as to allow of tacking from side to side.

Chisels, adzes, and other tools which are sloped only on one side, are in principle inclined planes.

The *Columbian printing-press*, which is one of great simplicity of construction and power, acts entirely on the inclined plane and lever.

THE WEDGE.

The wedge (fig. 44) is in the form of two inclined planes, *a b c* and *d b c*, joined at their bases. It is used to rend wood, rocks, &c.; also to raise heavy weights short distances, and compress substances closer together. More power is gained by striking the head of the wedge with a hammer, either small or large, than by pressure, as the momentum of the blow seems to shake the particles of matter and cause them to separate. A thin wedge requires less power to move it forward than a thick one, less resistance being offered, as in the case of an inclined plane. The power of the wedge cannot be correctly estimated, as the force, number of blows, and incline, have all to be taken into account. In splitting wood (fig. 45) the sides of the opening act as levers, and thus rend the parts in advance of the point of the wedge.

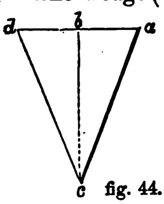


fig. 44.


fig. 45.

The wedge is useful in dockyards, where large vessels are raised by *its agency.*

The heads of hammers are fastened on by wedges driven in at the part of the handles near the heads.

Nails, knives, awls, needles, swords, razors, hatchets, chisels, and other similar instruments are, in their operations, on the principle of wedges. A saw is a series of wedges, which act by drawing them along and pressing them on the object to be cut. When the edge of a razor is examined by a microscope, it is seen to be a saw in formation, which by being drawn along the beard, enters the hair and thus cuts it off. A scythe acts in the same manner on grass. The saw nature of fine edges may be illustrated by pressing the thumb against a sharp penknife; the skin is not cut, but the slightest movement of the edge across the skin immediately cuts it.

THE SCREW.

The screw is placed under the head of simple machines, but cannot be used without the application of a lever or some other contrivance, when it becomes a compound engine of great power, either in pressing bodies closer together or in raising great weights.

A screw is in principle a projecting inclined plane *b b* (fig. 46) winding round a cylinder *a a*; for were it unwreathed, it would form an inclined plane, the length of which would be to its height as the circle of the

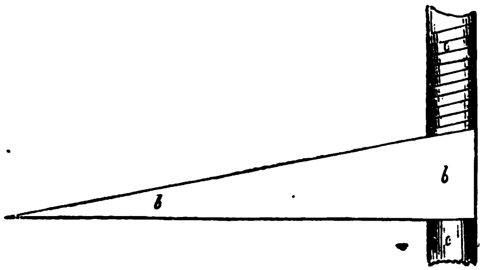


fig. 46.

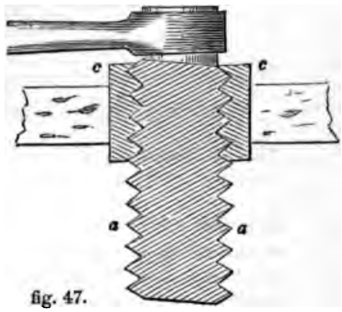


fig. 47.

cylinder is to the distance of one incline, or thread, as it is called, from the other. This spiral thread, or screw *a a* (fig. 47) works in another which is cut in the inner surface of a hollow cylinder *c c*, called a nut, or box, and sometimes a female screw. This portion is generally fixed. The one is formed exactly to fit the other. A lever *b* is placed in the head or other part of the screw, and every turn carries it forward upon the nut, or box, or draws it up to the extent of two turns of the thread. If the circle of the screw be 3 inches, and the distance of the threads half an inch, then the power gained will be as 6 to 1, as seen in the inclined plane; the height raised will be half an inch, but the whole circle of the cylinder, 3 inches or 6 half inches, has been passed over by the power, while the weight has only moved half an inch. Thus it is as 1 to 6 of *power gained*. But as the distance of the threads of the screw is lessened, *so is the* power increased. Suppose the distance of the threads to be a

quarter of an inch apart, and this to be turned by a lever 36 inches long, then the circle described by the lever will be about 216 inches, which multiplied by the quarter-inch of the screw gives 864 for the power gained, being 864 times as great as the distance between the spirals; therefore a power of 1 lb. at the lever would balance 864 lbs. acting against the screw, and the velocity of the power will be to the velocity of the weight as 864 to 1. Saying a man's pull or pressure to be equal to 120 lbs., and four men employed at the lever, then the pressure would be 864 multiplied by 120 four times over, equal to 414,720 lbs.

Formerly in the paper-mills, where it was requisite to have an enormous pressure, the lever was frequently 16 or 20 feet long, worked by eight or ten men assisted with a winch and pulleys.

A corkscrew is a screw without a central spindle or cylinder.

The screw is applied in pressing books, letters, &c. (fig. 48); packing light substances, as cotton, flax, and blankets, by which they are made to occupy a comparatively small space; also in wine-making to squeeze the grape, in cheese-making, and by the smith, carpenter, turner, and other artisans.

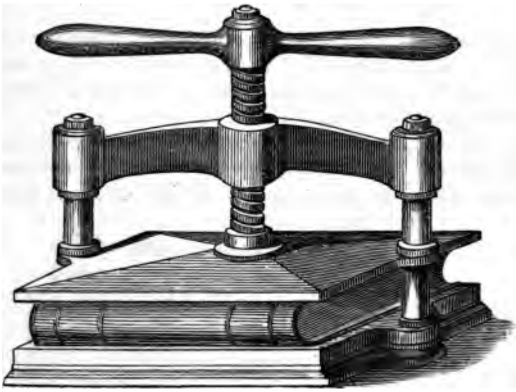


fig. 48.

It has also been the power by which the hand printing-press has been made, by which the curtain of ignorance has been lifted, and the light of knowledge diffused over the whole world. To effect this operation with rapidity, the thread of the screw is made very wide and others placed between, so that there are three screws, the great incline of the plane giving velocity, and the number of screws power. Thus in a moment, by a pull at the press-bar or lever, a pressure of a ton is given on the paper and type.

The screw is the means by which coin is formed and rendered legal by the impression upon it, letters copied, and dies imprinted on letter-paper and envelopes. The beautiful embossed boards, displaying great artistic taste in design and execution, so much used in the elegant ornaments conceived by ladies in the adornment of the drawing-room, are impressed by a large and much-inclined screw, similar to that of the printing-press, having a huge horizontal wheel as a lever power, swiftly turned by the strength of several men.

The screw also regulates many of the instruments of the mathematician, astronomer, operative chemist, and engineer, and is an invaluable assistant to the maker of delicate instruments, as by certain turns he can adjust his tools so as to mark a hundred thousand lines in an inch, the exactitude of which is all-important in the pursuit of scientific truths.

When the screw is applied to a toothed wheel, it is called a *perpetual* or *endless* screw, as it constantly moves in one direction, and keeps the wheel moving round.

If the winch (fig. 48a) be 20 inches long and the screw 2 inches in diameter, here is evidently a power of 20 gained; then if the wheel have 30 teeth and the screw at each revolution throws off one tooth, this is a power of 30 gained, which multiplied by 20, the other power, gives a power of 600. Again, say that the cylinder is only half the diameter of the wheel, that is an additional power of 2 to 1, by which multiply the former power, and the result is 1200 as the power gained by this machine.

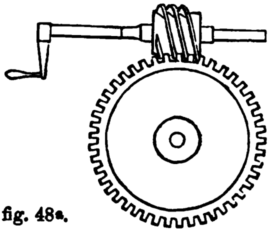


fig. 48a.

We have in conclusion to notice the "differential screw." From our previous remarks it will have been noticed that there are two ways of increasing the power obtained by the use of a screw, either by lengthening the lever or increasing the number of threads in a given space, that is by making the threads very fine. There are obviously limits to these: in the first place, by increasing the length of the lever the machine in which the screw is used would become very unwieldy; in the second place, the threads become weaker as they are finer. The differential screw invented by Mr. Hunter obviates these inconveniences; its principle is simply the employment of two screws, the threads of which are different in pitch. The principle is analogous to that of the Chinese windlass, the barrel of which has two diameters, one giving off as the other takes on rope; for the pressing surface is urged forward by the screw having the thread of greater pitch, whilst that with the smaller pitch draws it back to an extent corresponding to such pitch. Thus during each revolution of the screw, instead of advancing the action through a space equal to the pitch of either of the threads, it is really moved a distance equal only to the difference between

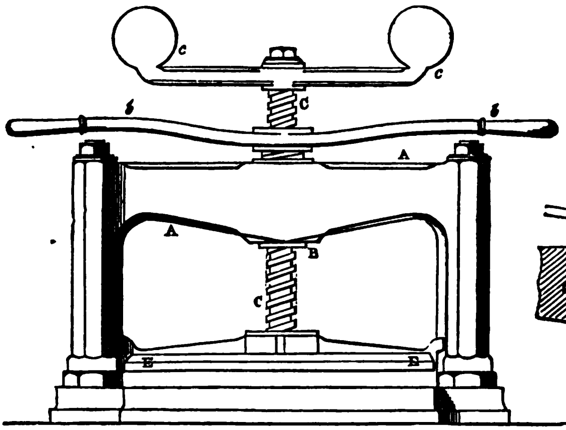


fig. 49a.

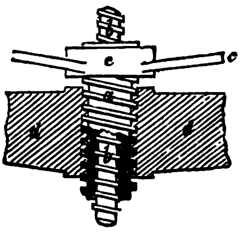


fig. 49b.

the two pitches, and the mechanical power is therefore equal to that ob-

tained from a single screw having a pitch equal to this difference. In this way power is obtainable to any extent within the practical limits of the difference between the pitches. This screw has recently been applied to a copying-press, of which we give an elevation in fig. 49ª, and a section in fig. 49ᵇ. The detail in fig. 49ᵇ will explain the operation of the differential screw movement. In the cross-bar AA (fig. 49ª), a screw-nut is fitted; this is worked by the double-handled lever *b b*; the upper lever *c c* works a screw C, which passes through the nut. The plate EE bears upon the object to be pressed by turning the lever *c c*; when the article is thus adjusted, the lever-handle *b b* is brought into play; the turning of this gives a differential movement to the screw CC, which is prevented from revolving by its friction on the top of the plate EE, against which it bears. In fig. 49ᶜ we show the application of this principle to the bookbinder's press, for which it is peculiarly applicable.

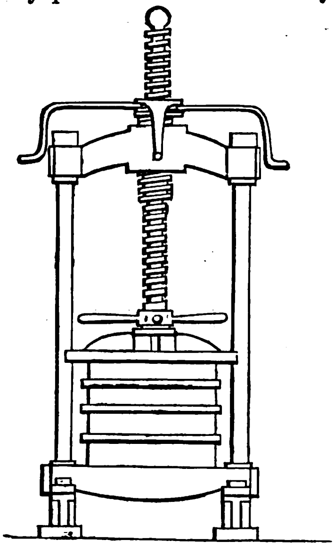


fig. 49ᶜ.

CHAPTER III.

REMARKS ON MECHANICAL POWERS.

Before describing and illustrating the application of the simple mechanical powers, the principles of which we have now discussed, to the varied forms of machinery, whether these be directed by the power of man himself, or by those willing natural agents which his intellect has appropriated or controlled to work his bidding, we shall give a few remarks explanatory of certain principles which it is essential for the reader to understand before endeavouring to become acquainted with the nature and construction of machines in which these principles are exemplified.

From the preceding pages it will be seen that the principles of the mechanical powers are resolved into two,—the lever, embracing the wheel and axle and pulley; and the inclined plane, to which belong the wedge and screw,—although the manner in which they operate differ greatly from each other.

It will also have been evident that what is gained in power is lost in time. If a man by a fixed pulley raises a certain weight to a particular height in three minutes, he may with three movable pulleys raise six times the weight with the same ease, but then he would be eighteen minutes in doing so; thus the work would be effected in the same time, whether the additional mechanical powers are used or not. But should the weight be in one piece, as a beam of wood, then one man by the additional pulleys effects what would otherwise require several men to accomplish. A carpenter with a lever may be fifteen minutes in moving a piece of timber a certain distance, whereas fifteen men would do the same work in one minute. It then appears that no labour is aved, but that mechanical powers allow a small power to labour a long time, and produce an effect equal to a concentration of power requisite to accomplish the desired effect.

No machine will enable a person to raise two pounds with the same velocity as the power that raises one pound, although a machine may allow the two pounds to be raised with half that velocity, or a hundred pounds with a hundredth part; still no greater quantity of motion is produced when the hundred pounds is moved than when the one pound is moved, as the heavier body moves slower in proportion.

In truth, labour is lost by machines, from the increase of friction adding to the amount of bodily exertion which has to be used, more than would be required if machines were done without. The value of machines consists in having the power of the concentrated labour of many men at command when perhaps it might be inconvenient to procure workmen or pay for their short engagement. Therefore one man labours the time of several men, and does a piece of work in twenty minutes which twenty men would do in one minute.

Machines give a convenient direction to the moving power, and allow

of the application of its action at a distance from the resistance. By them also the intensity of the moving power can be so equalised as to produce effects which otherwise could not be obtained.

By the control man gains from changing the direction of motion or force, he is able, by solid connecting parts, to arrange the wonderful, beautiful, and complex machines which vie in the formation of fabrics with the delicate nicety of the human hands. Man arrests the winds and stops the waters, that he may turn them to his own advantage. By steam he moves the ponderous and intricate machinery which weaves his garments, drains his land, defies wind and tides, threshes his corn, cuts iron as if it were paper, saws huge trees into veneers, bores his cannon, teems out miles in length of paper, and prints thousands per hour of the records of the world's progress, and then despatches it over the land with a velocity only excelled by that of the swiftest wind.

FRICTION.

So far we have given the comparative velocities of the power and resistance as they exist in *theory;* but in all mechanical powers, when put in operation, a deduction has to be made from the advantage gained for friction, which is a resistance to the free motion of a body.

Friction arises either from a cohesion of the substances touching each other, or from the roughness of the surfaces, although such parts appear to be smooth. When polished surfaces have been submitted to the powers of a microscope, they have been seen to have inequalities; and the little imperceptible hills fit into the hollows of the opposite surface, out of which it requires some force to lift or slide them, perhaps to break them off.

Friction is increased by the weight of one body pressing on another, and also in proportion to the velocity with which a moving body has motion.

The manner of measuring friction is by placing the substance, iron, wood, stone, &c., on an inclined plane; the utmost the incline can be raised without the body sliding is called the angle of repose, then according to this angle is the resistance of friction.

An experiment was tried of moving a flat piece of cast-iron, having a surface of 44 square inches, and weighing 24 lbs., on another piece, when it was found that a force of 51 ounces was requisite to slide it; the weight being doubled, 48 lbs., the force then required was 104 ounces,—proving that friction is nearly proportionate to pressure.

From the angle of repose, it is known when a screw will hold in a press without starting back when screwed down tightly; also from the shape of mountains whether they be formed of stone, sand, gravel, earth, &c.

It is the friction of the ground and the shoe that gives man a firm footing; when we step on a hole for admitting coals, covered by an iron plate, and the iron is smooth (thus giving little friction), we often receive severe falls. Glass and ice having little friction, cause a person when walking upon them to move with extreme caution.

Rivers flow smoothly and gently, from the friction presented by their banks and channels.

It is stated by Mr. Babbage, that a rough block of stone, weighing 1080 lbs., required a force of 758 lbs. to move it along the surface of its own bed; placed on a wooden sledge on a wooden floor, a force of 606 lbs. to drag it along; when the floor and bottom of the sledge were rubbed with tallow, 182 lbs. force moved it; and when on wooden rollers three inches in diameter, a force of 28 lbs. was sufficient.

Friction is reduced by polishing the surfaces; by applying oil, grease, and black-lead to fill up the little holes; and by making two different substances to be in contact, as the brass boxes in wheels, clocks, and engines, and the diamond in watches.

The smaller the diameter of the axle of a wheel, the less the friction.

According to the velocity, weight, and diameter of the axle is the friction of the wheel and axle.

Pulleys have very great friction, as have also wedges and screws: the latter have the most when the threads are sharp; but the endless screw has the greatest friction of any.

In going down a steep hill, the drivers of heavy vehicles pass a chain through a part of the wheel, which is to create friction between the wheel and the surface it is passing over.

If by calculation a combination of pulleys gives a power of 120 to 1, in order to overcome the friction and give motion, the power must not be considered more than 80 to 1.

In the finest surfaces that can be made, it is found that an eighth of the moving power is lost from friction.

To lessen the friction of wheels, there are sometimes used at the axle a number of small wheels, or friction-rollers, as they are called, that the axle of the carriage may rest upon them, and cause them to turn round their own centres when the wheel is in motion (fig. 50).

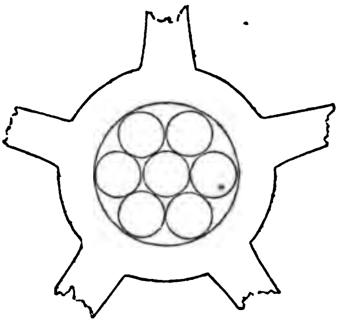


fig. 50.

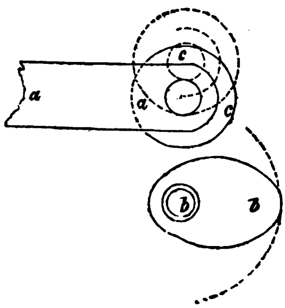


fig. 51.

Rollers or small wheels to reduce the friction are frequently used in mechanical contrivances. Thus, suppose a cam *b b* (fig. 51) by its revolution moves the lever *a a* up and down, a wheel *c c* is fixed at the end of the lever against which the cam works. The end view of this is given in fig. 51[a]. Small friction-rollers are placed at the lower parts of the *legs of tables, &c.*; these are generally called "castors," and serve, by

reducing the friction, to enable a heavy piece of furniture to be moved along a rough carpet with considerable ease. In the power-loom,

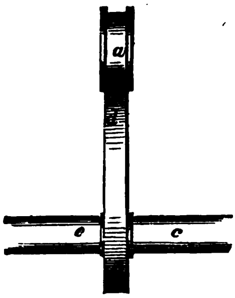


fig. 51a.

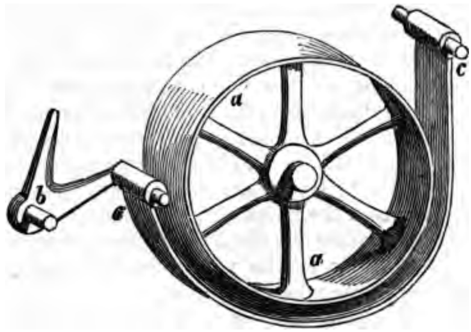


fig. 51b.

the pulley *a a* (fig. 51b) is stopped when required, by the friction belt *c c c* being tightened on the periphery of the drum by the lever *b*.

Friction-rollers are generally used at heavy gates, whether they slide sideways or open in the ordinary manner; in the doors of presses for papers, books, and other articles, when not opening on hinges; at the tops of windmills, which turn at every change of the wind; in observatories, where the motions of the heavenly bodies are followed; and in swing-bridges, dock-gates, &c.

The resistance of *air* and *water* may be said to be a friction which moving bodies have to overcome; but this, as in other cases, is reducible to a certain rule, for *the resistance is proportional to the square of the velocity*. Thus, if a steam vessel went at the rate of 12 miles an hour, and another sailed at the rate of 6 miles, the resistance to the one going 12 miles would be 4 times that of the one proceeding six miles; for the square of 12 is 144, and the square of 6 is 36, then 144 divided by 36 gives 4; thus the resistance to the one is 4 times greater than to the other. Consequently when velocity is increased, the moving power must be increased, not only to gain speed, but to overcome the increased resistance.

Naval architects have long studied and experimentalised so as to give such form to their vessels that resistance might be decreased; but many think that no shape will ever supersede that given by nature to the fowls whose living is derived from the waters, as displayed in the conformation of their breasts, or in the almost universal form of the head of fish, that have swiftly to move in their natural atmosphere of water: a sharpened nose on these animals may be likened to the cut-water of a ship.

The atmospheric resistance to a railway engine moving at 32 miles an hour is calculated at 353 pounds.

A cannon-ball meets with great resistance in passing through the air, but its great velocity causes it to vary considerably from the rule given above; while it is also supposed that when moving upwards of 1000 feet per second, a vacuum is created in its path which is productive of further hindrance to its progress.

Thus, then, by friction the foot holds the ground, poises the body, and allows its leverage to have a fulcrum, whereby we step forward with easy and safe locomotion. It is by friction that we can grasp anything; the hand of man is full of ridges, its softness yields to slight pressure, and thus its powers of opposition are increased. The savage warrior and more modern prize combatants greased their bodies, that friction might be less available to their opponents, and the chances of victory augmented to themselves. The want of it on the skin of an eel has been experienced by most persons, and the reduction of it by shaving and soaping the tail of a pig has afforded amusement to thousands. It is the friction of flax that gives its great utility when spun, and of the rope that enables the sailor to grasp it in his arduous duties, and that binds it on the windlass with the weight of the anchor in opposition; by it, too, stone holds to stone in forming the arch that spans our noblest rivers, and affords us solid and capacious habitations, while almost all the means of comfort or utility in our houses are held in their places by this power; it is the binding chain that must be torn asunder before motion can be given. The nail and screw have their usefulness from their power of friction. It is that which again restores rest to a moving body, when fresh force of motion is not added, as exemplified in the hoop and top of the boy, and the ball whirled upon ice. The brake by which the engineman arrests the velocity of his trains is a powerful application of this property of matter. Friction is one of the necessary conditions of earthly mechanism; it ceases in application to the heavenly bodies, and allows of that intermediate state between perpetual motion and eternal rest.

WHEELED CARRIAGES.

The substitution of wheeled conveyances for that primitive mode of locomotion, sledges, derives its value from the great reduction of friction.

A sledge touches every part of the surface it passes over, while a wheel measuring 16 feet in circumference, in once turning round, goes the length of its measurement, and is not dragged, but only changes the surface touching the ground, and the friction is at the axle and nave: thus, then, if the axle measures six inches in circumference, it turns in a smooth greased box six inches, while the carriage is moved 16 feet, making a reduction in the friction of 1 to 32.

A sledge is the best means of travelling on snow, because a broader basis is required than a wheel, which would sink into the soft substance: for this reason the Laplander fastens large pieces of flat wood to his feet. On ice there is too little friction to hold the small portion of a wheel that touches the surface; hence the sledge is found to be most fitting for such travelling. Our earliest projectors of railways, reasoning from the non-resistance of friction on ice, thought the smooth wheels of their carriages would not turn round on the smooth rails of their iron roads, and therefore placed cogs on the wheels and racks on the rails, that they might turn; this was soon discovered by practice to be an error in theory.

A wheel meets with obstruction at the point touching the ground, and

is covered to the top by the chain, and the newly wound-up spring in the other barrel being strongest at that time, unwinds it from a short lever, which the top of the fusee represents; gradually, as the spring loses its power, the lever becomes longer, and thus an equal motion is preserved.

MAGNETISM.—If a bar of soft iron, in the form of a horse-shoe, or rather that of a common door staple, be wrapped round with copper wire, and a current of electricity passed through the wire, the iron becomes a most powerful magnet, called an electro-magnet, and may be constructed so as to bear the weight of many tons. With this power, by making some magnets movable and others fixed, an attraction and repulsion has been created with such intensity, as to act as a great moving power, giving motion to large engines. It is plain that the force may be almost illimitable, but the expense seems to prevent the general adoption of this giant moving power.

Power is accumulative; that is, it may be collected in some machine, and then expended either gradually or by one effort, but to no greater an extent than has been accumulated. A man may find he has not power to push a stake into the ground; he therefore takes a mallet or hammer, and swinging it round, collects so much power and momentum with which he hits the stake, and so causes it to enter the ground. The hammer may have passed through thirty feet of space, and the power sends the stake a few inches into the earth; thus this forms a machine for a weak power to overcome a great resistance by a succession of efforts.

A man in leaping accumulates power by running a short distance first, and he expends it in one effort.

A sling is first moved gently, then more rapidly round and round, to collect power before the stone is allowed to fly.

A swing at a fair, filled with people, requires force to set it going; but it collects power and momentum, until it mounts so high as to become dangerous.

A *fly-wheel* is another reservoir of power, and is mostly used to equalise motion, as there is a continual pressure on the stronger part of its force to overcome the weaker, illustrated in a previous page by two men turning a winch. A fly-wheel does not increase the power of a machine, but distributes it regularly during its movement. The first putting it in motion is a loss; but still motion may be accumulated in it, by a continuance of power, sufficient to produce effects in raising weights and overcoming resistances.

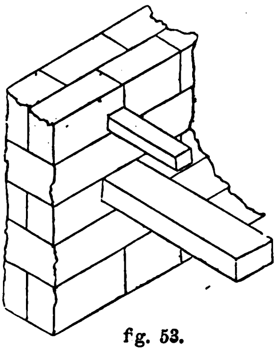
The wheel used in the screw-press for coining and embossing, previously noticed, is of this nature; as is also that in which a piece of flat silver is placed, and by a quick motion a perfect spoon is made. Some screw-presses are moved by having a horizontal lever of a bar of iron fixed at the axis, and at each end a heavy ball of iron; by drawing these balls back, then giving to them a quick forward motion, the power accumulated and the momentum is great, and the velocity considerable.

The grindstone and wheel of a lathe become a fly-wheel, or reservoir of motion, when once set fairly in action.

STRENGTH AND SIZE.

A limit seems to be set to the size of animals, man, and the works of man, as it is found that strength depends on the bulk, shape, position, and cohesion of materials. A compact useful-sized cart, if increased to four times the size, the strength of the materials must be increased sixteen times, and the weight consequently is increased sixty-four times; and if we proceed enlarging, the machine would ultimately break down under its own weight. It is a principle in mechanics, that weight increases in a greater ratio than strength, and therefore places a limit which demands the attention of all practical scientific men.

To some houses, more especially those formed to be let out into offices, having a common staircase, the stairs are formed of stone. If these stairs, which are inserted at one end into the wall of the building, were made to project too far, they would break of their own weight. A stone of a moderate size will be found to bear more than one double the length and double the thickness projecting twice as far out from the wall; for the larger one at the point of insertion, or fulcrum, in bearing the weight has to support, by the cohesion of its materials, twice as many particles beyond it, and each particle being pulled at by gravity, the length of the lever is increased, which renders it weaker than the smaller one. The centre of gravity in the large stair being much further from the point of support than in the small one, the weight is accumulated there. When mechanics calculate such an example as the present one (fig. 53) they proportion in solids the cubes of their sides, to find the contents of matter in each; therefore, in those two stairs there will be eight times as much in the larger as in the smaller one. The forces assisting to keep the bulks whole, therefore, are four to one in favour of the large stair; that is, it is four times less liable to break; but the stress upon the end of the large stair being eight times as much as on the smaller one, from its weight, and twice from the centre of gravity being at double the distance ($8 \times 2 = 16$), makes the liability to break from bulk and position sixteen times greater; then divide this disadvantage by its advantage ($16 \div 4 = 4$), it proves that there is a proportion of four to one in favour of the small stair.



fg. 53.

Following out this example, it shows that in all levers the strongest part must be where the strain is greatest; and in all machines, that the weight different parts have to bear must be taken well into account in proportioning them.

From this principle a limit is set to the size of the human frame, buildings, and machinery. It is this also gives size and form to mountains, trees, and animals. The oak that braves the tempests of centuries increases in bulk, but not in height. The massive megatherium, of immense structure, had bones proportionate to its bulk, but sloth-like crawled along the surface of the ground, leaving its path a cleared space, thus proving beneficial

to other animals, and by existing on roots thinned the forest, giving air and space to the remaining vegetation. The ponderous whale is borne by the surrounding water so as not to feel incumbrance from its size, and moves about with ease and velocity. Where the preservation of life often depends on agility, we find the slender and elegantly-formed stag; but where there is great bone, there is strength to defend the right of life, as in the elephant, rhinoceros, and hippopotamus. We are somewhat grieved that philosophy robs the fables of the heathen of their celebrated Goliath deities, and produces unbelief in the exciting romantic deeds of the hero Jack the Giant-killer. We are compelled to think the latter warrior "made the giants ere he killed them."

STRENGTH OF BODIES.

Solids will bear an immense amount of pressure before the shape of them can be changed permanently. In a cube of one inch in size, the following solids have been found to require a pressure equal to that placed opposite each to effect an alteration in their shape:

	lbs.		lbs.
Elm	3240	Tin	2880
Ash	3540	Zinc	5700
White Fir . . .	3630	Brass	6700
Oak	3960	Cast Iron . . .	15,300
Red Fir	4290	Malleable Iron .	17,800
Lead	1500		

The manner in which experiments can be tried as to the resistance of metals in a flat shape to that of a tubular is very simple. Two solid pieces of iron are placed at a little distance from each other, and joined together at the bottom by a hinge; on the ledge, half way up, a flat piece of the metal is placed, and then weights applied at the top, until the strength is proved; the tube, as seen in the diagram, is next put between the solids, and weights placed until tested.

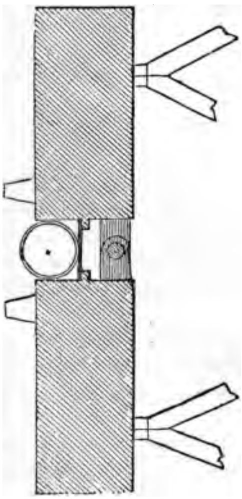


fig. 54.

Wood is found to afford the greatest resistance when placed in an upright position, and that it is strongest when of a short length.

In our mines, where there are immense numbers of supports required to hold up the superincumbent mass of the roof in the excavations, short props are invariably used. The reason of the superiority of a short piece of timber to a long piece used as a support is, that the force acting upon it does so equally on the whole, and has little mechanical advantage. In the short piece every atom resists, and therefore the impenetrability of matter has to be overcome; whereas in a long piece the leverage is greater, and it is more apt to bend, the slightest yielding in a great number of atoms making a considerable

total. If a long piece bend in the centre, then it may be considered that the pressing weight acts as a lever against the strength from the mark in the centre to the outside bend, while the lever of the short piece is its entire length and thickness (fig. 55). By applying any stay or projection which will strengthen the part likely to bend, firmness is added to the support.

When a piece of timber is bent by pressure, the atoms in the inside

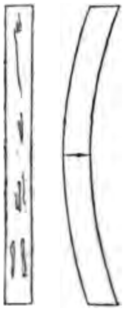


fig. 55.

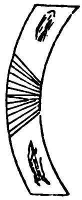


fig. 56.

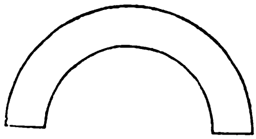


fig. 57.

curve are pressed together, while those at the outside are separated and stretched out, as represented by the radial lines, fig. 56; the middle portion is neutral, and might be removed without lessening the strength of the timber. It is on this principle that hollow pillars are made. A solid piece of iron formed into a tube has greater strength, as a mechanical support, from having a longer lever, by the substance standing further from the centre. In fact, hollow tubes combine lightness, saving of material, and strength, far beyond the material as a solid body. Tredgold states that when the inner half diameter of the hollow cylinder is to the outer as seven to ten, it will possess double the strength of a solid cylinder of the same weight.

A fluted column, from offering a greater resistance to a bending force, is found to be stronger than one perfectly smooth.

From this combination of advantages, the Divine contriver has made the bones of man and animals hollow, being strong and hard externally, and light and honeycombed internally, while the bone of the upper arm in man has ridges, which add to the strength.

The quills of birds are another beautiful illustration of a careful use of material with strength and elasticity; had they been formed the same size as they now are, but solid, they would have been unfitted to soar in the aerial atmosphere, tread lightly on the ground with their slender limbs, or swim upon the surface of the waters.

The hollow stalk of corn rears its slender form two or three feet with its valuable cereal head bending gracefully to the stormy wind.

The common mint has an angular stem, ribbed with fibres and filled with pith.

The willow and elder-tree are slim and light of construction; and the bamboo and sugar-cane have manifold usefulness from their construction.

On the same principle that a large column is more liable to break *than a small* one, and that forces increase more to break bodies than

those which keep them entire, the child is in less danger from accidents than a man.

When a beam is supported at both ends it is twice as strong as one half its length supported only at one end. Still, if a beam be too long, supported at each end, it will, from its own weight, break in the centre, or weakest part.

A beam or a plank supported at its ends will bend down in the middle (fig. 58) when the atoms in the upper side will be pressed

fig. 58.

together, those on the under be pulled out, and those in the middle, called the *neutral axis*, undergoing no change, might be taken away without much diminishing the strength. From each end to the centre might be called levers, and from the centre to the upper part, the resisting force, having very little assistance from the under half. When much bent the fibres underneath are so stretched that a penknife passed across will make them fly asunder, and the plank or beam snap in two.

In forming the roofs of large buildings the beams are made to lean against each other, as a letter **A** : by this arrangement the pressure is applied to the grain of the wood endwise, and consequently supports a greater weight; cross strains are made as much as possible to convey their weights into beams, having a longitudinal position, and the skill in doing this renders the buildings more stable; in truth, a well-constructed roof may be considered as a bone hollowed out, where substance would not add to strength.

A plank bears a greater weight when resting on its edge than on its side. In the flimsy shells now erected called houses, hardly strong enough to resist a gale of wind, and leaning against each other for support, this is taken advantage of; for, instead of good firm joists, a piece of wood not thicker than a good plank is put in; but as they would be apt to curl and thus start out of the wall, they are held in their position by cross binding pieces in the centre. And this is the improvement of the age in house-building!

If we take the bent plank in fig. 58 and turn it upwards, we form an arch. This form given to a fixed body is capable of enduring an immense transverse pressure, because force compresses the atoms both of the under

and upper side, which prevents their separation; and as every atom thus bears its share of the strain, it becomes equal to an upright support.

Man in forming bridges may have derived the hint from nature, as there exist several fine arches. The grandest in size is that in Virginia, United States, being 270 feet high, 90 feet span, 60 feet broad in the centre, and forty feet thick. On this gigantic scale does nature work.

The arch acts with pushing force against the piers of the bridge; and in domes, which are on the same principle as simple arches, the piers not generally being thought sufficient to resist the horizontal thrust which exists, other means are taken, as having girders inside crossing over. At St. Paul's, London, two powerful chains pass around the exterior, resting in the stone-work.

The strength of the arch is exemplified in the safety of materials packed in a cask compared to that of a square box; in a watch-glass, bottles, and many of the common utensils in domestic use.

Nature adopts it as the most safe protector of incipient life in the eggs of birds. In the vegetable kingdom the vital principle is wonderfully preserved in an arched case. The elegant rounded finish to that master-piece of creation, man, where sensations and action have their termini—the brain—is carefully and powerfully protected by the beautiful, light, graceful arch which forms the skull of the human form.

In concluding the subject of Mechanics, we may observe that the whole rests on very simple laws.

A mass of matter when in motion may be compared to another mass, either with respect to the size and weight of each other or the swiftness with which they move. The greater the mass, the greater will be the force required either to give it motion or restore it to rest; while the swifter its motion, the greater will be its force. The momentum is calculated by multiplying its weight by its velocity of motion. When bodies act in contrary directions, as when weights are acted upon by a lever, wheel and axle, pulley, &c., the ascent multiplied by its weight, and the descent multiplied by its weight, if equal, balance each other; because, as both actions take place during the same period of time, their velocities are as to the space passed through, and the preponderance of weight in one body is equal to the greater velocity of the other; and thus extra velocity and space balance the lesser velocity and space, but greater weight.

This, then, shows a great fact in all mechanical contrivances, and places the power of accurate computation within the reach of an earnest investigator; for by knowing how much swifter the power moves than the weight, or how much more space is passed over by the moving power than the power moved in the same period of time, the exact increase of assistance gained by the machine is known. But we entertain a hope that the familiar examples we have given throughout the chapter, illustrative of this important and pleasing branch of science, will have fixed on the mind, without much effort, the principles by which it is universally governed. The laws of mechanism are beautiful from their very simplicity.

CHAPTER IV.

PARTS OF MACHINES IN WHICH THE SIMPLE MECHANICAL POWERS ARE EXEMPLIFIED.

Applications of the Lever.—In almost every machine, however simple, the lever is seen applied; its modifications are very numerous. In the apparatus for opening and shutting valves in steam-engines, and other prime movers, the lever is the principal part. Thus in fig. 59, where *a b c* is a lever-handle of the form generally used, suppose the end *a* is firmly fixed to a rod capable of revolving, by moving the end *c*, it will describe part of the circle shown by the dotted lines; while at the same time the rod to which the end *a* is fixed will revolve. For the convenience of handling the lever, a projecting handle or lever *d* (fig. 60) is

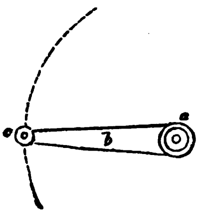


fig. 59.

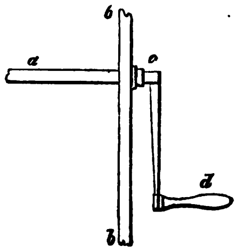


fig. 60.

placed at the end *c* (fig. 59). The diagram in fig. 60 illustrates the method adopted in starting and stopping the engines of a locomotive: *b b* is part of the boiler through which the rod *a a* passes to the valve to which it is connected; a lever *c* is moved by the handle *d*, and being connected at *c* with the rod *a*, it causes this to revolve and moves the valve, of which in its proper place we shall give a description. In fig. 61 we show another method of giving motion to valve-rods by means of levers; this modification is in use in locomotives. Suppose *f* to represent the end of a valve-rod connected with the lever *e*, the valve being placed at the front of the engine, while

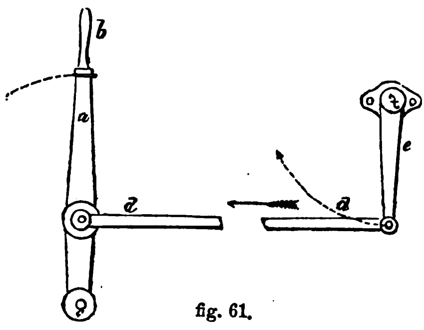


fig. 61.

the engineer stands at a distance from it, as towards *a*, near the fire-box; a rod *d d* is connected with the end of the lever *e*, and is fastened by a *movable joint to a part of* a lever *a*, the centre of motion of which is at

c; the engineer, by pulling the handle *b*, in the direction of the arrow, will cause the lever *d d* to move as in the diagram, and *vice versa*. In some cases a small wheel *a a* (fig. 62) is attached to the rod *b*, to be moved; a handle *c* is fixed on one of the arms at any desired distance from the centre; a leverage is obtained equal to the space between the centre of the wheel and the point at which the handle is fixed. This method is frequently adopted in slide lathes, the wheel being fixed at the end of the screw which moves the central spindle; in some cases (fig. 62) the handle *c* is dispensed with, the arms of the wheel itself being used to turn it round. This adaptation may also be seen applied to the brakes used in locomotives and railway-carriages.

The application of the lever is also observable as a principal feature in

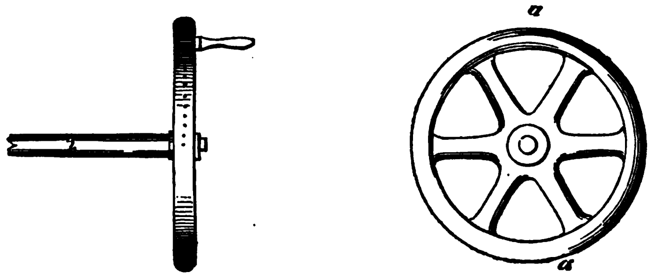


fig. 62.

the steam-engine; thus in fig. 63, which illustrates the beam with its usual appendages, termed the "parallel motion," the lever plays an important

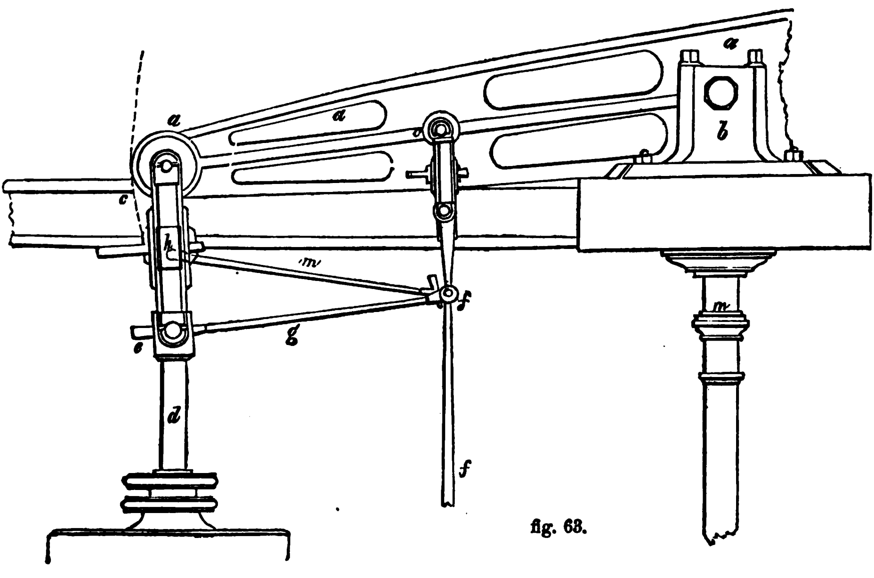


fig. 63.

part. The great beam *a a* is a lever, the centre of vibration of which is at *b*; the links *c c* are also levers, the centres of which are at the ends of the lever *g*, and at the points where they are attached to the beam; the centres of the lever *m g* are at *h* and *f*. The result of this combination my be here generally stated; although the end *a c* of the beam describes a part of a circle at each vibration, yet the piston-rod *d* traverses up and down in a straight line. In the proper place we will fully investigate the *rationale* of this elegant adaptation of one of the simple mechanical powers. In the "governor," another important appendage of the steam-engine, the lever is the principal feature; in an advanced portion of this treatise we will explain the principle of its action. In the safety-valve of the

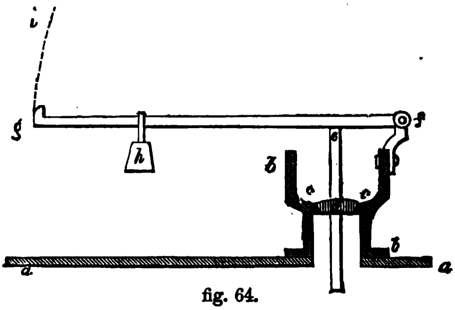


fig. 64.

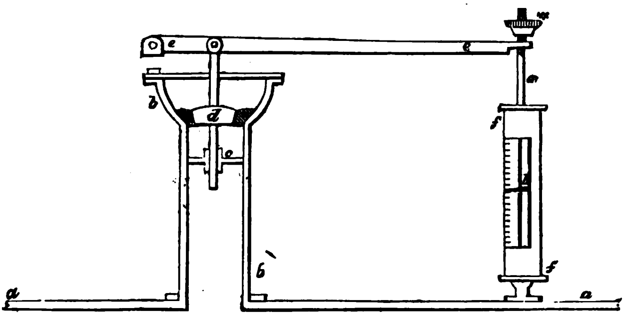


fig. 65.

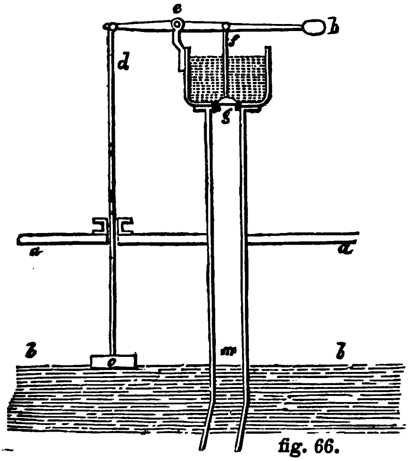


fig. 66.

steam-engine boiler, fig. 64, and in that of the locomotive, fig. 65, the lever is also noticeable as the main feature. In fig. 64, the steam pressing upon *d* causes the spindle *e* to move the lever *g* in the direction of the dotted line *i*; the centre of the lever is at *f*, and the weight at *h*. In both these kinds of valves the levers are of the third order. In the self-acting feed apparatus attached to boilers of steam-engines, the lever is also employed; thus in fig. 66, the water *b b*, rising or falling in the boiler *a a*, acts upon the float *c* and the spindle *d*, which is attached to it, and also to the

end of a lever which vibrates in the centre *e*; this, again, acts on the valve *g* by the rod *f*.

In the diagram fig. 67, we give an arrangement of levers which act very powerfully; they are used in the Stanhope printing-press. The short lever *a b* is attached to the head of the screw which acts on the platten, which presses down the paper on the inked types. This short lever is connected by the rod *c c* with the bent lever *f e d*; the power applied at *d* having to move through a much greater space than the screw at *b*, considerable power is obtained by this combination. In fig. 68, the arrange-

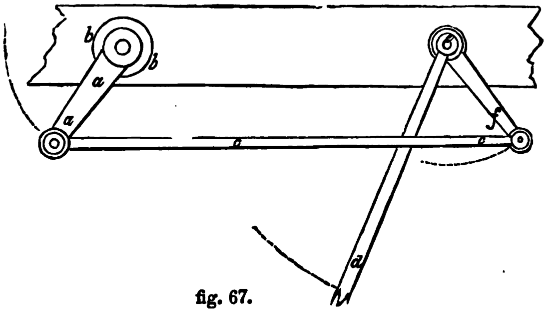
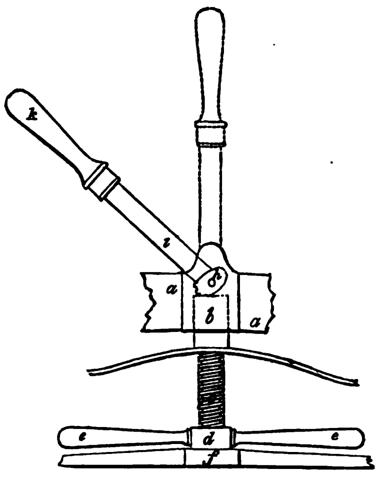


fig. 67.

ment of levers in the well-known "copying-press" is shown: the plate *f* is first pressed in close contact with the article subjected to pressure by means of the lever *d e e* acting on the screw *c*; thereafter the lever *k i* is



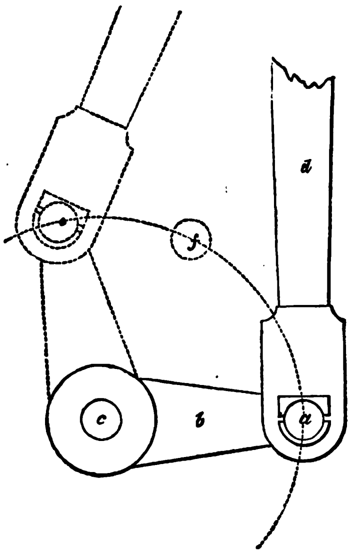


fig. 68. fig. 69.

brought into action, which acting on the screw by means of the cam *h*, depresses the plate *f* with great pressure.

A crank is a simple lever; thus if the end *c* of the lever *c b a* (fig. 69) be fixed to the end of a shaft to which it is desirable to impart rotatory motion, and a "connecting-rod" *d* be attached by a movable joint to the other end *a*, by causing the rod *d* to move up and down, or in other words to have a reciprocating motion, the end *a* will revolve in a circle, as shown by the dotted lines and figures: a fly-wheel is required where the motion is to be continuous and without jars or jolts; the reason of this being required is explained at p. 48. The contrivance known as the "bell-crank" is a modification of the single crank. The crank-arm *a b*, fig. 70, being at right-angles to that of *a c*, the connecting-rod *e* being moved in a horizontal reciprocating direction will cause that at *d* to have a vertical motion, or *vice versa*; the ends *b c* of the cranks will only describe portions of circles, proportioned to the length of stroke of the connecting-rods. The form of crank used for steam-engines of considerable power

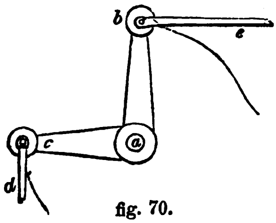


fig. 70.

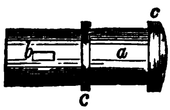


fig. 72.

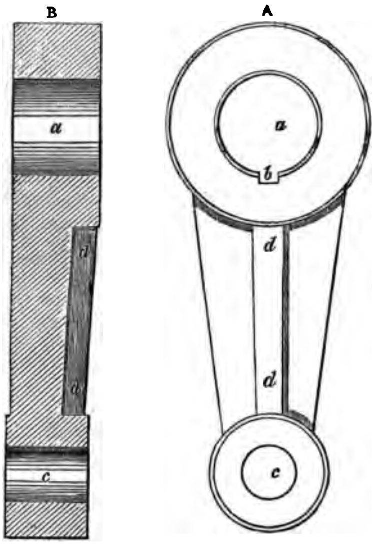


fig. 71.

is shown in fig. 71, of which A is a front view, and B a section. The crank is passed over the end of the shaft which it is designed to turn at the eye *a*, and secured by a key, as will be hereafter described. The crank-pin, to which the end of the connecting-rod is attached, is passed through *c*, and fastened by means of a key or cottar; *d d* is a rib or projection, which gives strength without incurring much weight. The crank-pin is figured in fig. 72; *b* is the part fastened in the eye *c*, the connecting-rod brasses (hereafter described) embrace the part *a*. Fig. 73 shows a method adopted in marine engines of attaching the connecting-rod *a*, to the end of the beam *b*; while in fig. 74 the method of attaching the other end of the rod to the crank is shown. In fig. 75, the mode of attaching the connecting-rod of a large beam steam-engine to the end of the beam is illustrated: *a* is the end of the beam, *b b* the pin or journal,

c c c the connecting-rod. The bent rod observable in the knife-grinder's

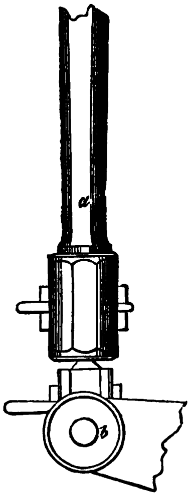


fig. 73.

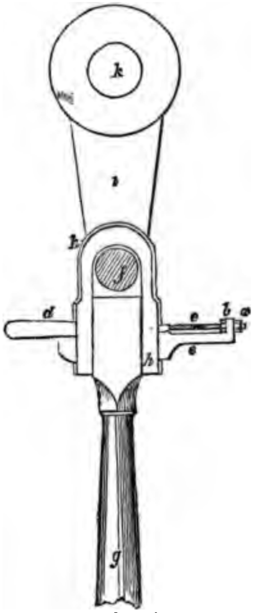


fig. 74.

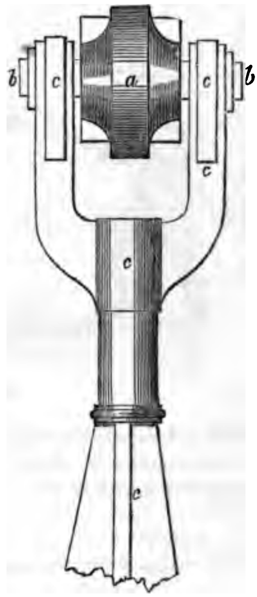


fig. 75.

machine is also a crank; the operative, by alternately raising and depressing his foot on the jointed foot-board *a a*, fig. 76, imparts a recipro-

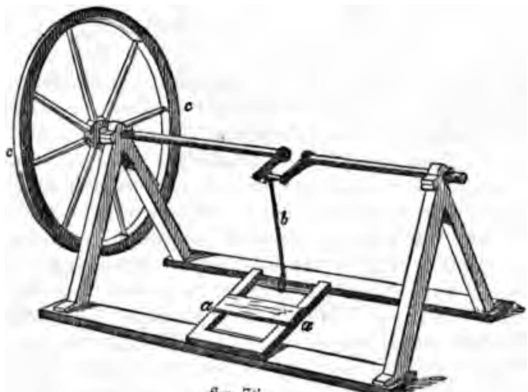


fig. 76.

cating motion to the rod *b*, which turns the axle and fly-wheel *c c*. In the "potter's wheel" the crank is also used to drive his machine; by turning the crank-handle *a a*, fig. 77, motion is imparted to the fly-wheel *b b*, from which motion is communicated to the machine by the strap, or belt, *c c*. The bent handle used in turning grinding-stones, coffee-mills, &c., is a crank.

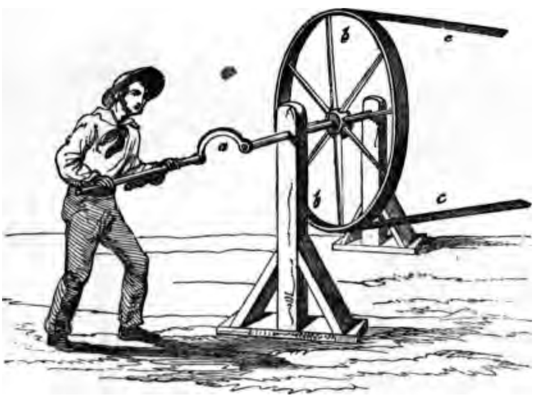


fig. 77.

The instrument used by mechanics for shifting moving nuts upon bolts, and called a "key," "spanner," or "monkey," is a lever. A common form is shown in fig. 78: a recess *a* is made at one end, by which the nut *b* is grasped; the power is applied at *c*, which performs part of a circle, of which the centre of the nut *b* is the centre; the nut revolves on the bolt, and is tightened or loosened at pleasure. Keys are sometimes made in the form of a bent lever, as *e g f*; recesses of different sizes being made at the ends, in order to grasp nuts of various dimensions.

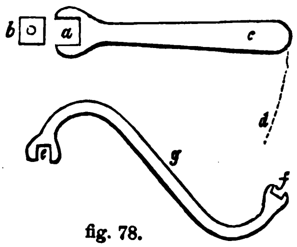


fig. 78.

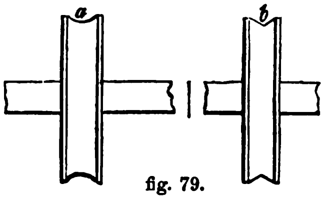


fig. 79.

Application of the Wheel.—In the various departments of practical machinery, the adaptation of the wheel to many purposes is very noticeable. We have already given exemplifications of this mechanical power in figs. 27 to 31. They are used in numerous ways to transmit power from point to point, to change the direction of motion and its relative velocities. Pulleys or drums, as used for this purpose, are merely wheels and axles; in fact, the axle or fulcrum is always an inherent part of every wheel or pulley, without which it could not be used. Pulleys used in machines are of different forms; those in blocks used on board ship, or in cranes on land, for lifting heavy weights, have either angular grooves cut in their periphery, as *b*, fig. 79, or concave, as *a*. In factories they are generally made, as in fig 80, with a comparatively thin rim *a a*, attached to the centre *c* by the arms *b b*; an aperture is made in this, through which the shaft *c c* is passed, as already noted (see fig. 62). Motion is communicated by means of leather straps or belts from one wheel or pulley to another. If the outside of the pulley was made quite flat, that is parallel with the shaft or axle, the belt would have a continual tendency to slip off the surface; to prevent this, advantage is taken of a curious property observed in these contrivances, which causes the belt always to remain on that part of the periphery which is highest;

hence in all well-constructed pulleys the outside rim is turned so as to be convex, as *d d*, fig. 80. In cases where the strain is severe, the belts are apt to slip on the surface of the wheels. Where this embarrassment is merely temporary, from increase in the work to be performed, or from other causes, engineers generally obviate it by strewing the inside of the belt with pounded resin; this is taken

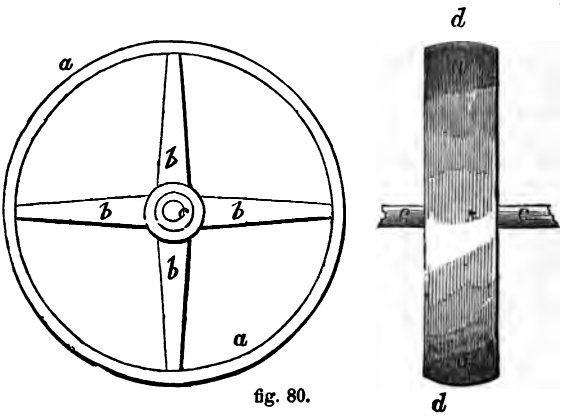


fig. 80.

up by the wheel surface, and considerable friction is induced, which enables the belt to take the necessary "grip." But in cases where the power is too great to be transmitted by belts, other contrivances are adopted. The first of these we shall notice is the linked-chain motion, as being closely allied in principle to the belt. If we could suppose little protuberances or projections to be made on the periphery of an ordinary pulley, and similarly disposed apertures to be made in the belt, then as the wheel revolved the projections would be caught by the apertures, and slip would be prevented: theoretically this plan is available; in practice, however, its defects are obvious. Fig. 81 shows one of the methods adopted in practice by which the idea is carried out: the projections *b b b* in the links *a a a* are made to fit in the indentations *d d d* of the wheel *c c*; as the links are jointed in many places, enough of flexibility is imparted to the chain to enable it to pass easily round the wheel *c c*, of which only a part is shown in the diagram.

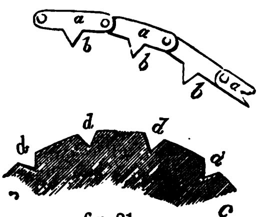


fig. 81.

In place of belts, and the rather cumbrous contrivances of linked gearing-chains, now described, motion is transmitted from one point to another by means of toothed wheels. Where the driving wheel is large, it is called the "wheel" *par excellence;* the driven wheel being smaller is termed the "pinion." Thus in fig. 31, *a* is the pinion, and *b b* the driving wheel. Wheels thus working revolve in contrary directions; by the interposition of a third wheel, *a*, the last revolves in the same direction as the first.

In future departments in this treatise we shall have occasion to illustrate various adaptations of toothed wheels to different machines. To reduce the friction as much as possible between the rubbing surfaces, the form of the teeth has been always an important consideration amongst engineers; much attention has, consequently, been given to the subject by learned men, the most practical of whom may be said to be Professor Willis. To this branch of engineering he has contributed much of

value. Where the teeth, or projections, of the wheel are formed as part of the wheel, that is, when both are cast in one piece, they are designated as "teeth," the projections of the pinions being in like manner termed "leaves." When the teeth are made of wood, and inserted in holes made in the periphery of the wheel, they are termed "cogs." In some cases, instead of a pinion, a modification termed a "trundle" is used; some engineers (among others Smeaton) prefer it to a pinion, as it is considered by them to wear more equally. On this point, however, difference of opinion prevails. In fig. 82 we have shown the form of a trundle; it consists of round spindles of wood or metal, *c c*, their ends firmly inserted in flat pieces, *a b*. In some cases small wheels or rollers are made to move one another without the intervention of belts or teeth. This is effected by one of two methods,—either by making them slightly fluted in their exterior surfaces, or by covering them with leather; in either case they work in contact, and the friction produced suffices to cause them to revolve, motion being first imparted to one by some prime mover. This principle is met with in most of the "machines of preparation" in cotton - spinning factories. In some machines motion is to be transmitted from one point to another, while at the same time the shafts or axes are not parallel, but at right angles to one another. This necessitates the employment of a different form of toothed wheel; this is called the "bevil" or "mitre" wheel. The rolling surfaces, as will be observed in fig. 83, are parts of cones; thus *b b* fixed on shaft *a a* gives motion to *c c*, fixed on shaft *dd*, at right angles to *aa*. In fig. 84 the form of these wheels as generally used is shown.

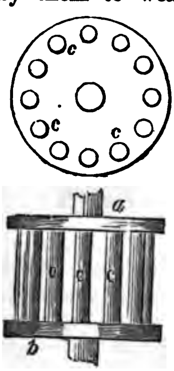


fig. 82.

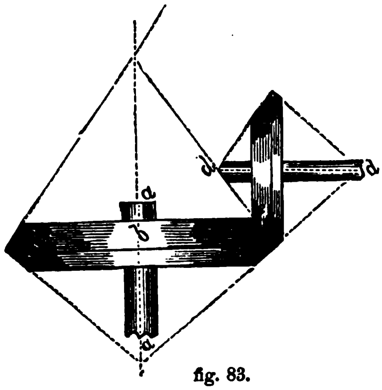
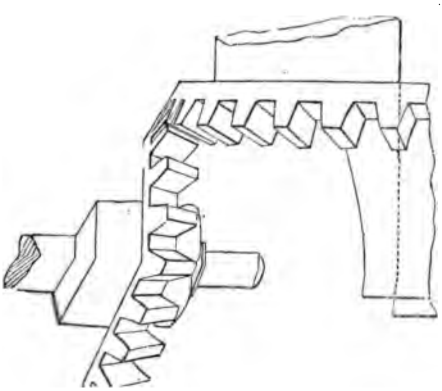
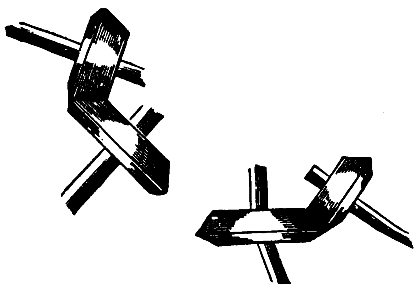


fig. 83.





As may be seen in figs. 85 and 86, bevil wheels are useful in transmitting motion in various directions. The "trundle," in conjunction with the "face wheel," as it is termed, has been frequently used in corn-mills for changing the direction of motion by toothed wheels : this is illustrated in fig. 88. Another and a familiar method is that known as the "crown-wheel," much used in the cheaper kind of watches, called "verge" or vertical : it is shown in fig. 87.

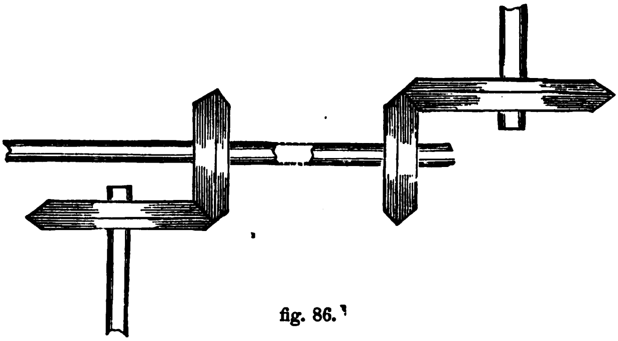


fig. 86.

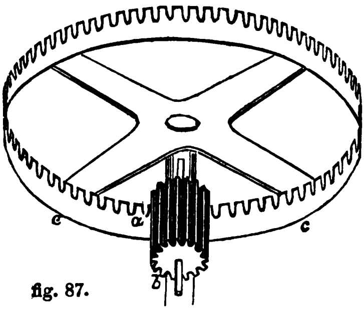


fig. 87.

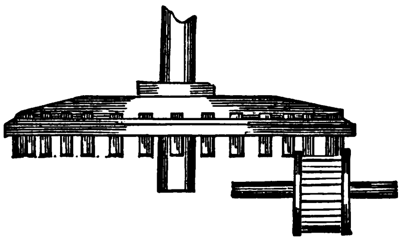


fig. 88.

Applications of the Wedge.—A modification of the wedge frequently met with in machinery is what is termed a "key" or "cottar." It is shown in fig. 89 at *d d* ; *a a* is another form : by striking at one end, the "gibs" *b c* are tightened ; that is, *c* is forced down, while *b* is forced up, and *vice versa*. In fig. 90 its use in tightening up the brasses of a connecting-rod is shown ; c c, d d, e e,

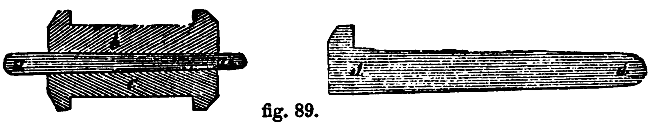


fig. 89.

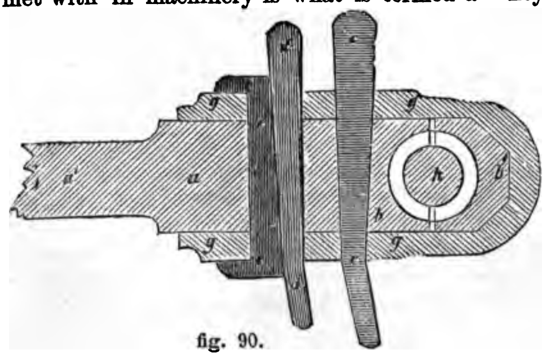


fig. 90.

are forms of wedges, *d c* being the keys or cottars, and *e e* the gib : this arrangement will be explained more fully hereafter. "Cams," used for giving alternate motion to parts of machinery, are modifications of the

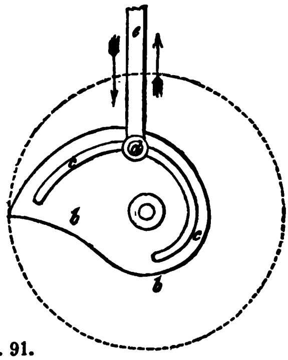


fig. 91.

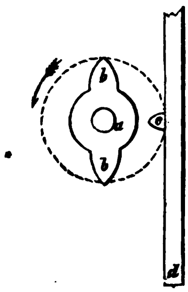


fig. 92.

wedge. In fig. 91 is shown a modification : *b b* is the cam, having a groove *c c* made in it; in this groove a pin *d* works, attached to the rod *e*. In some cases cams are termed "wipers," as in fig. 92 : *b b* are the wedge-shaped wipers projecting from the wheel or shaft *a* ; these strike alternately on the wiper *c*, projecting from the rod *d*. Another modification is shown in fig. 93, where *b b* are the "wipers" on the surface of the shaft *a*. In fig. 94 a view of a washing-machine is given, in which the "beaters" *b b* are made to rise and fall by the revolution of "lifters" placed on the axis of the driving-wheel.

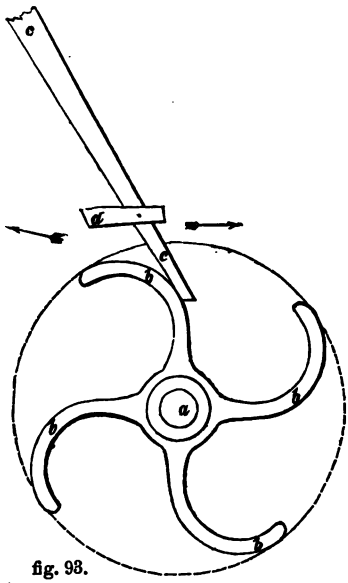


fig. 93.

The "ratchet-wheel" may be called a modification of the wedge. Wedge-shaped teeth *b b* are cut in the periphery of the wheel *a*, fig. 95, the object being to prevent it from turning in any but one direction; for this purpose a "catch" or "detent," *c*, is fastened to a beam, or part of a frame over the wheel. Suppose the wheel to be moving in the direction of the arrow, the end of the detent freely allows each tooth to pass it : but on the wheel beginning to move in a contrary direction, it catches in the bottom and side of the tooth, and prevents it moving. This movement is used in cranes and windlasses, where it is essential to prevent the rope unwinding ; it is also used by the mechanic in boring holes in metal, as will be described hereafter.

Applications of the Screw.—The screw is much used in machinery in

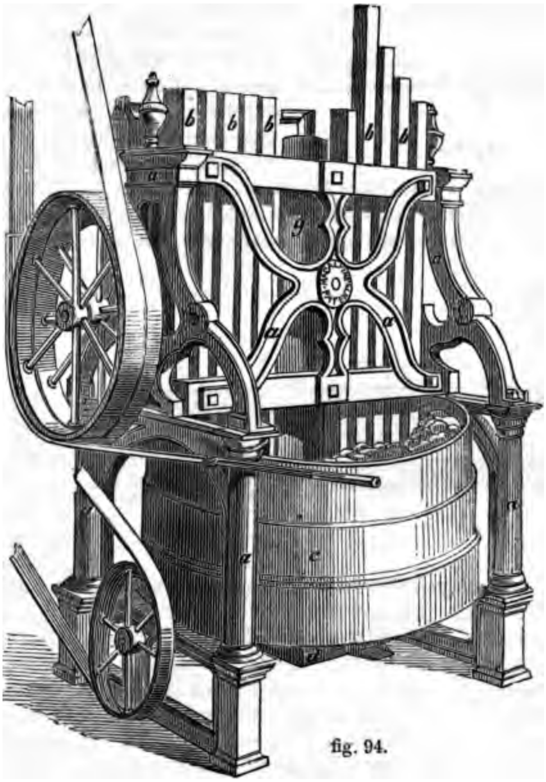


fig. 94.

fastening and tightening various parts. In fig. 96, *a b c* shows the general form of "bolts" used in machines: the screw is cut at the end *c*; a head is formed at *a*; the part *b c* is passed through a hole made in the parts to be joined together, as *e e*, *f f*; by tightening the nut *d* the parts are fastened together and firmly secured: nuts are sometimes made square, sometimes

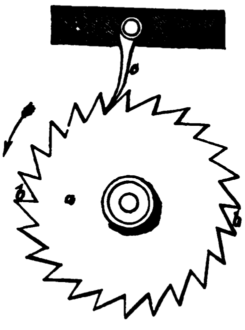


fig. 95.

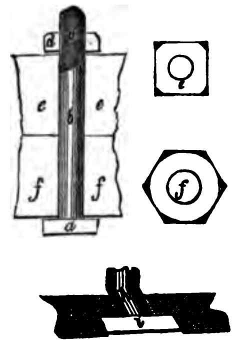


fig. 96.

hexagonal and octagonal, as *e*, *f*. A shifting "key," in which the screw is made available, is shown in fig. 97. In fig. 98 two forms of keys for moving nuts are shown; in these, certain sizes of nuts only can be taken or grasped; but the form in fig. 97, which is technically called a "monkey," or "shifting spanner," is available for varying sizes of nuts. The fixed jaw *a* is riveted to the stock *b*, one end of which has a screw cut on its surface; this works into a corresponding internal screw cut in the shoulder of the

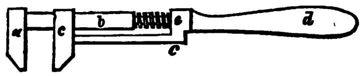


fig. 97.

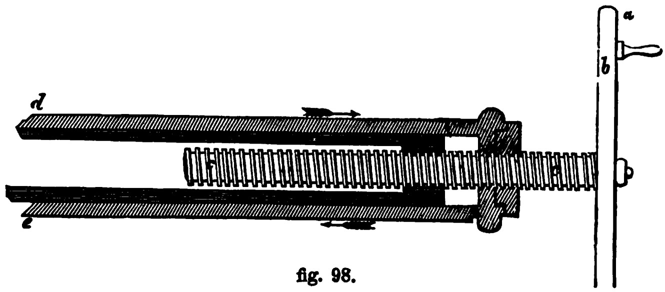


fig. 98.

handle at *e*; this plays between a grooved part on the arm *e* of the sliding bar *c*, attached to the jaw *c*, which moves along the stock *b*; by turning round the handle *d*, the sliding bar and jaw *c* is made to move either to or from the fixed jaw *a*; by this means the distance between them can be proportioned so as to enable any size of nut to be grasped between them. The internal screw is used in turning-lathes; this is exemplified in the section of part of the "head" given in fig. 98. The spindle of the lathe-head works in an accurately-bored aperture made in the head, as at *d d*; one end, *h h*, of the spindle is made with an internal screw, which fits the male screw *c c*; by turning the wheel *b b* fixed at the end of *c*, by the handle *a*, the spindle is either projected further from the hollow head or drawn within it.

CHAPTER V.

CONSTRUCTION AND ARRANGEMENT OF ESSENTIAL PARTS OF MACHINES.

In communicating motion from one point to another, and for supporting the assemblage of wheels, pulleys, and the various modifications of mechanical powers which may be adopted for this purpose, contrivances known as "shafts" are used. When of considerable diameter, this is the term by which they are known; when of comparatively small dimensions, they are called "spindles." Shafts are of two kinds, "horizontal" and "vertical:" the former being used when motion is to be communicated from one end of a room to the other, or similar positions; "vertical," where it is to be taken from a low to a high position, as from the engine on the ground-floor of a factory to the various floors above.

Shafts, up till a comparatively recent period, were generally made of wood. Excepting in very rare instances, and those chiefly in rural districts, this material is now seldom used, cast and malleable iron being alone employed. The former is generally adopted in the case of heavy shafts, while the latter is almost always employed for shafts of comparatively minor diameters. Shafts are composed of two portions—the "body" and the "gudgeons," or "journals." The latter term denominates the parts on which the shafts revolve, and in small iron shafts are formed by merely making a certain portion circular and smooth by being carefully turned in a lathe. Thus, in fig. 99, *c c* is the body of the shaft, while *b b* are the

fig. 99.

"journals." When shafts are made of wood, oak in a solid mass is used, or they are *built* of lengths of fir. Sometimes they are made octagonal, or have the corners roughly taken off; more generally they are left square. As it is evident that the journals must be of some better or more durable material than that which forms the body of the shaft, cast iron is usually adopted for this position; hence arises a necessity for having an efficient method of fastening the journals, thus necessarily separate, to the body of the shaft, in such a manner that they shall, as nearly as possible, approx-

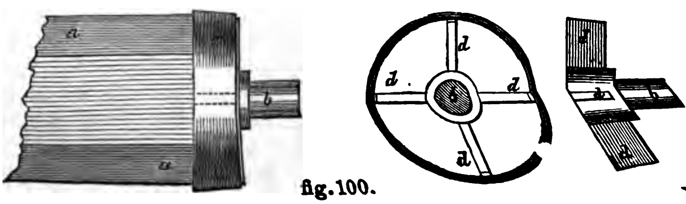


fig. 100.

imate to the condition of a shaft perfectly solid and stable throughout its length. We here figure one of the methods adopted to attain this desideratum. Thus, suppose *a a*, fig. 100, to be part of a wooden octagonal shaft, mortices or apertures are made in the end of the shaft of a certain depth, and of shape and width corresponding to the "cross-tails" *d d* cast round the journal *b*; these arms are let into the mortices on the end of the shaft and driven home; a hoop of metal, *c c*, is put over the end of the shaft in a heated state, then carefully wedged up; on cooling, the hoop closely binds the end of the shaft and the ends of the cross-tails *d d*.

When large shafts are used, as in water-wheels, where the motion is slow, they are made of cast-iron and *hollow*. In this case the journals are sometimes inserted, as shown in the sketch, fig. 101: *b b* is a project-

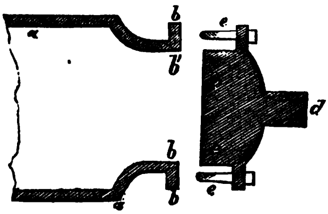


fig. 101.

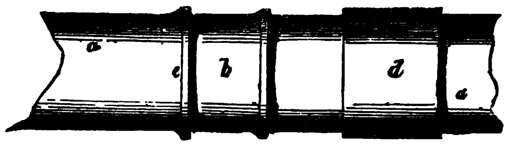


fig. 102.

ing flange, cast round the end of the shaft *a a*; the interior of this is carefully bored, to receive the part *c c* of the journal *d*, which is turned of the same diameter as *b b′*; the parts are held together by the bolts *e e*, passing through the projecting flanges, and secured by nuts.

The method of fixing wheels, pulleys, &c., on shafts is simple. In every shaft there is provision made for this. In fig. 102, the part *d* is that on which the wheel is to be fixed: it is called the "boss," and is of larger diameter than the body *a*; *b* is the journal, terminated by two projections, commonly called "ruffs" or "collars." As the "eye" or centre of a wheel to be fixed on a circular shaft is generally bored out, it is necessary that there should be some means adopted to prevent the wheel from turning round or shifting on the shaft. This is effected by cutting, in the first place, a longitudinal "slot," or groove, along the inside of the eye of the wheel or pulley, as in fig. 103 at *b*; this may be done at only one side, or at both ends of the diameter; in some cases four are made: the parts cut out are termed "key-seats." Part of the boss of the shaft is next made flat by means of appropriate tools; the wheel is put on the boss with the slot opposite this flat part; a key, as *d*, is then inserted in the slot and driven home; acting as a wedge, the wheel is prevented from slipping round the shaft. In some cylindrical shafts, ribs or

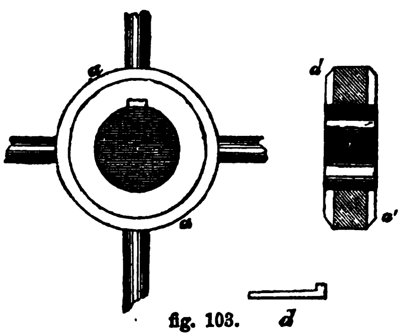


fig. 103.

projections are cast, as in figs. 104 and 105, *b b* : fig. 105 is a section of fig. 104. Where shafts are made square, as in fig. 106, the eye of the wheel

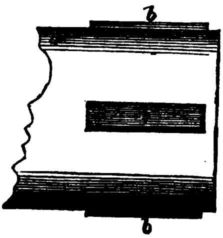


fig. 104.

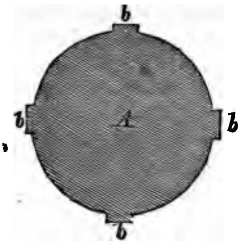


fig. 105.

being made square, by cutting key-seats in it, it may be fixed easily on any part: *c c* are the journals, *a a* the body of the shaft, *b* a section

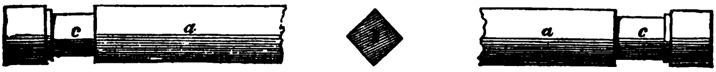


fig. 106.

through the body. As a general rule, the journals of shafts should be of the same diameter: enough should be merely taken off to form them, leaving depth enough to keep the journals in the brasses.

This brings us to the next important feature in this department of machinery, namely, the "bearings" by which shafts are supported and in which they revolve. They are generally known as "plummer" or "plummet blocks," or "pedestals." They consist of two parts: the "sole," *a′ a′*, or part which is bolted down to the standard or frame *e e*, fig. 107,

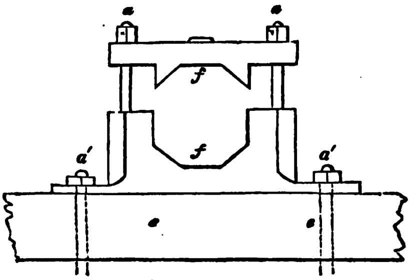


fig. 107.

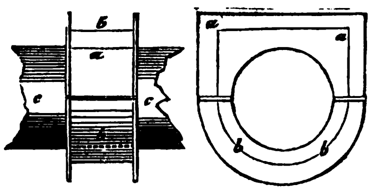


fig. 108.

by the bolts *d d*; and the "cover" *a*, which is secured to the sole by bolts passing through it, as in the sketch. The journal of the shaft revolves in a space *f f*, left in the centre of the block. In order to prevent, as much as possible, loss of power by friction, the shaft journal is made to revolve within "brasses," or "pillows," made of brass, or a mixture of copper and zinc. *In fig.* 108, a front and side view of a brass generally used is given. *The part b is* that which is placed in the sole of the block; *a* that placed

in the cover. They have both projecting flanges, which embrace the sides of the block; *c c* is the journal. In some cases the brasses are made octagonal in form, as in fig. 109, where *b b* are the upper and lower brasses, and *d* the journal. It is evident that as the sides of the brass will em-

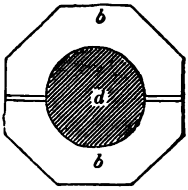


fig. 109.

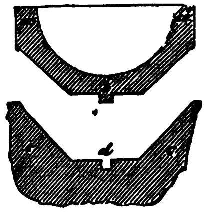


fig. 110.

brace those of the block, as *f*, fig. 107, the brasses will be prevented from turning round. Another method of keeping the brasses in their place is shown in fig. 110, where a projecting snug, or rib, *b* is made beneath the brass *a a*; this fits into a slot *d*, made in the cover or sole of the pedestal, part of which is shown in the figure. This plan is generally used where the brass is made circular; this allows the space in the block to be accurately bored out to the size required.

The method by which the brasses of connecting-rods, &c., are made to embrace the journals may be described here. Suppose *m*, fig. 111, to be the journal or crank-pin, *b b* the lower half of the brass, *d d* the upper half; a strap *a a*, of which the usual form is as in fig. 90, is made with

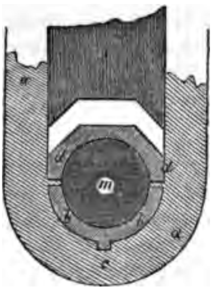


fig. 111.

fig. 112.

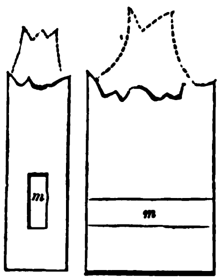


fig. 113.

one end circular, which embraces the lower brass *b b*; a space *a a*, fig. 112, is cut out on each side; the butt *e*, of the connecting-rod, which is more fully shown in fig. 90, is of breadth sufficient to pass easily down between the sides of the strap; a space is also cut through this, as at *m*, fig. 113, at such a distance from its extremity, that when placed within the strap at its proper place, the space through it and those in the strap coincide. The end of the brass being kept in its place by the projecting rib *c*, fig. 111, it is very frequently made with projecting flanges, as in fig. 108; in this case the breadth of the strap *a a* is so that it can pass easily between the flanges. The manner in which these parts are kept together is as follows: the brasses are made to embrace the journal; the

strap is then passed over these, so that the inner curve presses against the outer curve of the lowest brass; the butt of the connecting-rod is then passed between the sides of the strap; keys are then passed through the space, or slot, and driven home. When the brasses begin to wear, and the journal works loose between them, by tightening the keys the brasses are brought close together; to admit of this, they are originally fitted so as to leave a space between them, as in the sketch. In fig. 90, to which we again refer, we have shown a method of fitting the brasses, connecting-rod, and strap of a locomotive engine: *h* is the journal, *b′ b* the brasses; a strap *g g g g* is passed round these, embracing the lowest, *b′*; the connecting-rod, *á a*, is secured to the strap by the cottar *d d* and gib *e e*; when the brasses become loose, the wedge, or key, *c c*, is driven in, and presses upon the upper brass *b*. When the key and gib, *d d*, *e e*, are in their proper places, they are secured by small force-screws. In fig. 114 we show another form of connecting-rod butt, strap, and brasses: *m* the end of the journal, *e é* the brasses, *f f* the strap, *b* the butt of the connecting-rod *a*; by driving home the key *d d*, the gib *c c* is tightened; this lowers the strap, and tightens up the end on the brass *é*. In fig. 74, another method is given: this is sometimes used in locomotives, but chiefly in large marine and land engines: *i k* is the crank, *f* the crank-pin, *g* the connecting-rod, *h h* the strap; the key *d* is furnished at its extremity with a screw *e*, which passes through the end of the gib *c*; while the nut *a* is tightened, *b* is loosened; the pressure thus

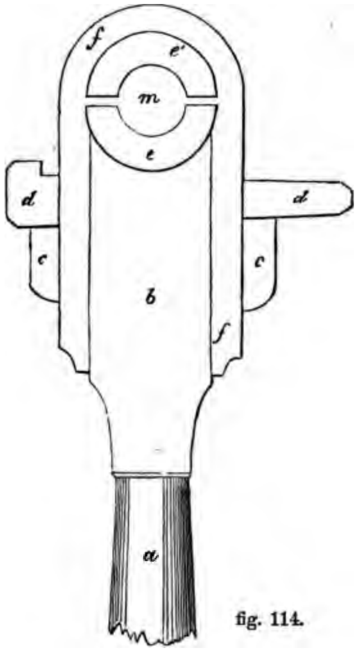


fig. 114.

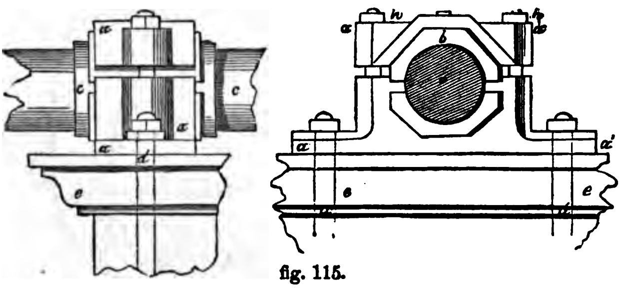


fig. 115.

transmitted to the gib *c*, tightens up the strap in the brasses embracing the journal *f*. In fig. 115 we give a front and end view of a plummer-block, showing the connection of all its parts: *e e* is the standard, or frame,

to which the sole *á á* is bolted by the bolts and nuts *d d*; the cover *a a* is bolted to the sole by the bolts *h h*; *b b* the brasses, or pillows. As these wear, they are brought in closer contact with the journal by tightening the bolts *h h*; *c* the shaft. Another form, showing a method adopted of making the bearing in a steamboat engine, is given in fig. 116: *a a* is part of the side-framing, *b* the shaft, *c* the cover, *dd* the bolts for securing this.

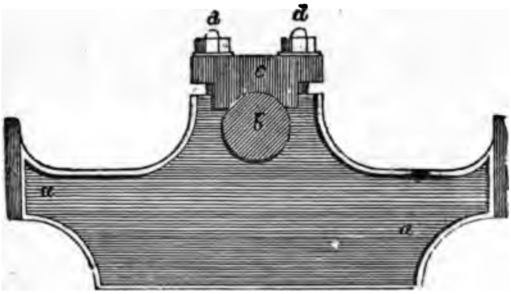


fig. 116.

The bearings for vertical shafts are formed by having the brass generally hollowed out, somewhat like a cup, placed in a footstep *b*, fig. 117, which is secured to a footbridge of cast-iron *e e*, adjusted in the plate placed on the block of stone *a a*. The end of the shaft *d* is formed so as to work easily in the cup-shaped brass.

In order to adjust plummer-blocks upon the stands to which they are fixed, it is usual to adopt a foundation-plate, on which two projecting snugs are cast; the sole of the block goes into the space between them, and wedges or keys are driven up at the ends; thus any lateral adjustment can be made by driving the keys correspondingly. When the height of the block is to be altered, pieces of wood or thick mill-board are placed between the sole and foundation-plate.

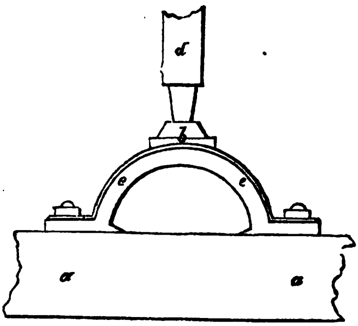


fig. 117.

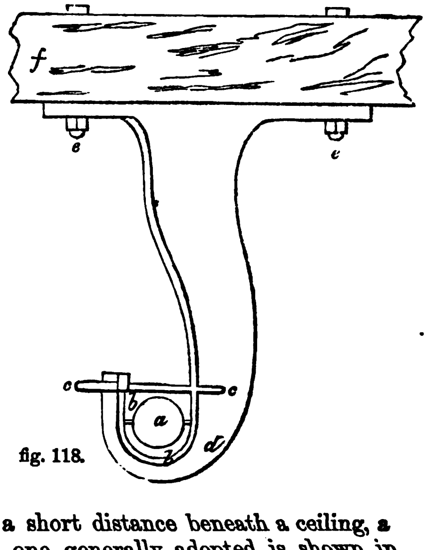


fig. 118.

When shafts are to be carried a short distance beneath a ceiling, a different form of bearing is used; one generally adopted is shown in fig. 118. It is denominated a "gallows," or pendent bracket: *f* is the

beam or joist to which the gallows is suspended; the plate of the gallows *d* is fixed to the beam by the bolts *e e*; *a* is the revolving shaft, *b b* the brasses, *c c* the key by which the brasses are brought in close contact with the journal as the former wear away. Where shafts are carried along the front of a wall, the bearings are what are termed brackets, as in fig. 119, where *a a* is the wall, *d* the bracket projecting from it, sufficiently to allow wheels, pulleys, &c., to revolve freely without coming in contact therewith. A wall-plate, as *b*, is used to serve as a foundation on which to adjust the bracket; it is bolted firmly to the wall, and the bracket adjusted thereto by bolts and keys.

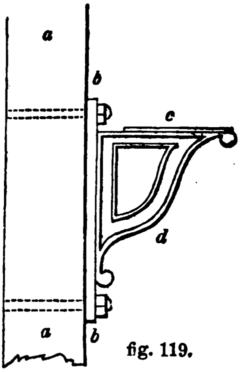


fig. 119.

In cases where only one end of a shaft is supported by a separate frame, as in some kinds of simple high-pressure steam-engines, the other extremity works in a bearing placed in an aperture made in the wall opposite to which the framing is placed; the aperture in the wall is provided with a cast-iron box, of depth equal to the breadth of the shelve, which serves as a foundation-plate on which to adjust the block. Thus, in fig. 120, *a a* is the wall, *b b* the wall-box, *c* the plummet-block, *d* the shaft, the other end of which revolves in a bearing placed on the top of the framing of the steam-engine, or otherwise placed as the case may be. In some cases where the shaft has to be continued to the other side of the wall, for communicating motion to machines there placed, the wall-box is simply a frame or box contained within four sides, and provided with a shelve as above stated; in place of a separate shelve, the bottom side of the box is made to serve as the plate on which to adjust the bearing, as in fig. 120.

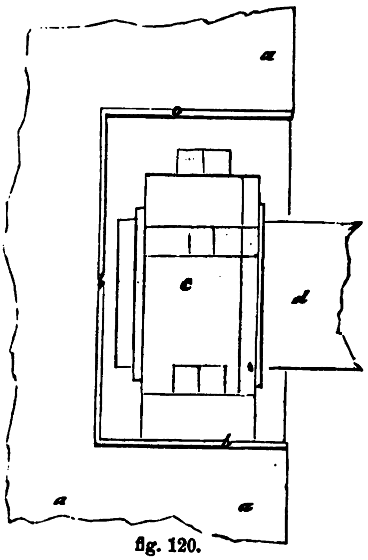


fig. 120.

Where shafts are required of too great a length to admit of their being cast or made in one piece, contrivances are resorted to by which two or more lengths are joined together. These are known as "couplings."

Couplings are of two kinds or classes; those having two bearings, and those having one: by this time the pupil will understand the term bearing, meaning thereby the plummer-blocks or pedestals on which the journals of the shafts revolve. Theoretically, the construction of couplings is a matter of extreme simplicity; on the supposition that the shafts remain *always as fitted* up at first, it is an easy matter to adopt means by which *shafts can be* coupled together effectually. But in practice the difficulty is

increased from the wearing of the journals, brasses, sinking and altering of foundations, and from other causes; many adverse circumstances are called into play, which make it a matter of practical difficulty to find a form of coupling which will answer to the expectations of theory. Hence the number of variations of couplings: to notice a few of these will suffice for our purpose.

The "square coupling" is shown in figs. 121 and 122, the latter being a transverse section through the centre of the coupling; the ends *a′ a′* of the shafts *a a* are made square, and put together end to end; they are then embraced by a "coupling-box" *b b*, placed diagonally on the shaft; the inside of the box is fitted to the exact size of the squares of the shafts; it is also provided with flanges, through which bolts are passed, and secured by nuts *c c*. In some instances the coupling-box is made in one piece,

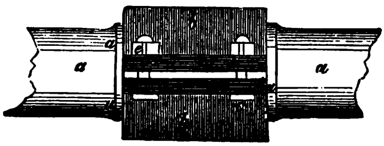


fig. 121.

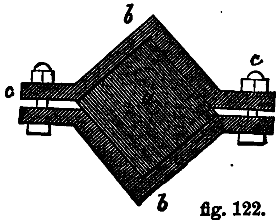


fig. 122.

and the square parts of the shafts are together rather longer than the length of the box; this enables the latter to be slid past the joint and allows the two shafts to be disengaged without removing the box. This form of coupling, though apparently simple and effective, is liable very speedily to get out of repair, inasmuch as the bearings are apt to wear unequally; the result of this is, that in such revolution one or other of the shafts will be lifted off its bearings; this produces unsteady motion, and hence farther twisting and wearing of the coupling. This form is therefore rarely used in heavy mill-work, being chiefly confined to small machinery. The "round coupling" is shown in fig. 123, part of which is shown in section, the upper figure being a cross section. In this form the ends of the shafts are made cylindrical, and faced so as to lie close up to one another; a coupling-box is passed over the ends and secured by pins passing through the box and shafts at right angles to one another. In this form the shafts and box can be more accurately fitted; but as the strain is obviously concentrated on the pins and holes, the former in a short time become loose, and have to be replaced by new ones; these, of course, not being fitted with the same accuracy to the holes as in the first instance.

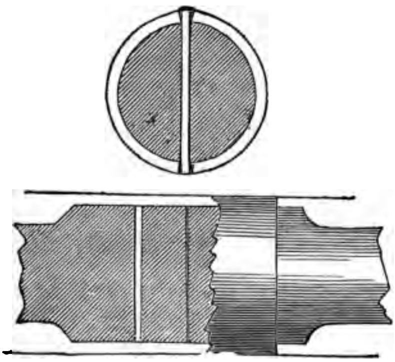


fig. 123.

In some cases, shafts having two bearings—as those last described—are coupled together without the use of coupling-boxes; in this case the couplings are denominated "clutches," or "glands." "Glands," says an eminent authority, "are an excellent mode of coupling for double bearings, and have the advantage of throwing the stress farther from the centre of motion than in the square coupling as commonly executed." In fig. 124, *d* and *c* are parts of the shafts to be coupled, having the bearings at *c*, *d*; at the ends of the shafts, round plates *a*, *b*, are cast; in the face of these, projections and recesses are cast; the projections go into the recesses, thus locking the two plates fast. Another form is given in fig. 125: the shafts *d′ a*, having their bearings at *d e*, have crosses *c c*, *h h*, attached to the ends; one of these, as *h h*, has its extremities curved; these, as may be seen, catch hold of the extremities of *c c*; thus, one shaft set in motion actuates the other.

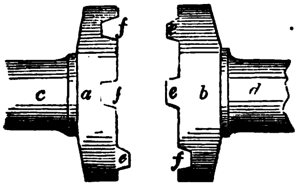


fig. 124.

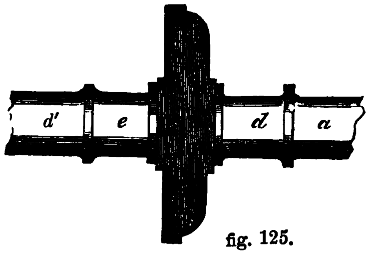


fig. 125.

Couplings having two bearings being attended with much friction, they have been to a certain extent abandoned, and those having only one bearing used. The square and round couplings already described, by some small modifications can be adapted to couplings having only one bearing. In fig. 126, a modification of the square coupling is shown: the end *b* of the shaft *a* is made square, and provided with a projection *d*, which fits into a recess made in the end of the shaft *c*; a coupling-box passes over both squares, and is secured either by two pins passing through it and the shafts at right angles to each other, or by keys. The journal or bearing of one shaft is near the square, while the other is farthest from it. In fig. 127, the round coupling for one bearing is figured; it is called the "half-lap;" the shafts *a*, *c* are cylindrical at the ends, and are made with semi-cylindrical extremities *b*, *d*, so that when laid together they form a perfect circle; the round coupling-box *ee* embraces both extremities, and is prevented from moving by the key *f*. When carefully constructed, this coupling is not only elegant in

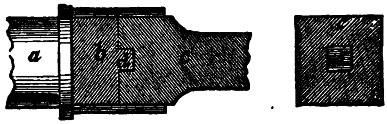


fig. 126.

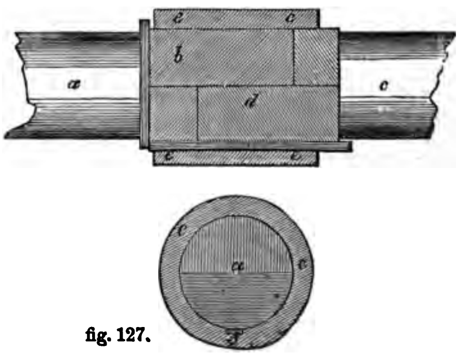


fig. 127.

form, but comparatively durable; it is now almost universally adopted in the better class of modern mill machinery.

Where shafts require to be coupled, which are inclined to each other in their line of direction, the contrivance known as the "universal joint," invented by Dr. Hooke, is sometimes employed. A modification of this joint, as applicable to heavy mill-work, is shown in fig. 128; strong plates *c b*, are cast on the ends of the shafts *a a*; these have bearings *d d*; *e* for supporting the journal or gudgeon. In cases where this joint is used, the angle of inclination of the shafts should never exceed 15°; when above this, a double joint should be adopted, or a pair of bevil wheels acting as in fig. 129.

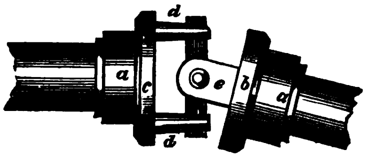


fig. 128.

When the engagement or disengagement of certain parts of machinery is desiderated, other forms of couplings are adopted: these we shall explain and illustrate in another part of this treatise.

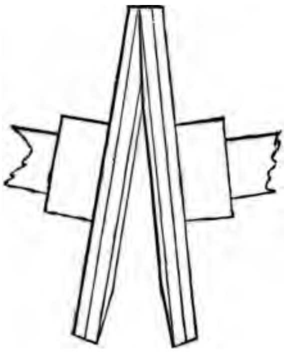


fig. 129.

As oil and other lubricating substances are employed in reducing the friction between the journals of shafts, and the brasses, or pillows, of the bearings on which they revolve, various plans are adopted for economically applying the lubricating substance or fluid to the parts required. The simplest method adopted is by boring a hole in the upper part of the cover of a block, or the shafts of a connecting-rod or side lever, *b b*, fig. 130, as at *c*. This is generally made tapered, and is what is termed counter-sunk at its upper part *a*: this forms a kind of cup in which to

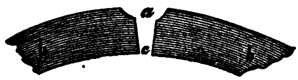


fig. 130.

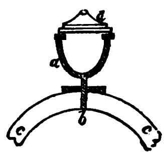


fig. 131.

retain the oil. An ornamental cup is sometimes placed above the aperture, as in fig. 131, where *c c* is part of the strap of the rod, *b* the aperture, *a* the vase, or cup, *d* its cover. In place of having the oil to run directly to the part to be lubricated, thus creating a considerable waste, an ingenious and philosophical contrivance is adopted: in this, advantage is taken of the property of capillary attraction possessed by some bodies. An ornamental cup or vase *a a*, fig. 132, is fastened at its base *b*, to the part to be lubricated; a tube *c c*, fig. 133, communicates with the part to be lubricated, and reaches nearly

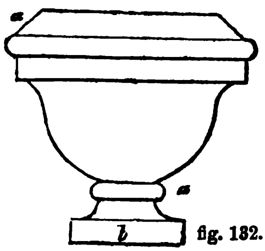


fig. 132.

to the top of the vase; a roll of worsted is passed through this tube; one end is nearly in contact with the rubbing surface on the journal of a

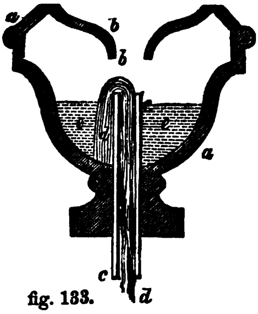


fig. 133.

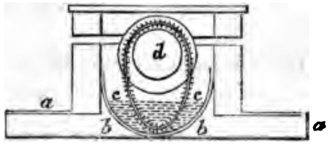


fig. 134.

shaft, and the other reaches nearly to the bottom of the vase. The oil is conveyed throughout the whole length of the worsted. In mills, the oil is supplied to the bearings of shafts from a can with a long spout; to save as much as possible of the oil dripping from the shafts, a receptacle is placed below. To obviate this inconvenience and loss, Messrs. Vaughan and Hossack of Manchester have devised a very ingenious lubricator: we show it in fig. 134. Suppose *a a* to be the plummer-block, in which the shaft *d* revolves; a circular receptacle *b b* is placed beneath this; a metallic endless chain *c c* passes round the axle, and dips into the oil placed in *b b*. The shaft revolving, keeps the chain continually dipping different parts into the oil: a supply is thus continually taken up to the shaft.

CHAPTER VI.

CONTRIVANCES FOR EFFECTING VARIOUS MOVEMENTS IN MACHINERY.

IN this department of our work we intend to explain and illustrate various combinations of those parts of machinery which we have already noticed, adapted to some particular motion. In every machine at all complicated, the movements are numerous: in examining these in detail, some parts are seen having a uniform motion; in some, wheels are revolving now fast, now slow; one part having circular motion is seen imparting that which is reciprocating, while on the converse, reciprocating is changed into a circular movement; again, wheels revolving with amazing rapidity are seen to be connected with others turning at a slower speed. In some machines, as in those of the cotton-manufacture, the movements are so complicated, and apparently confused, that to the eye of the uninitiated there is presented nothing but an interminable range of whirling wheels, shafts, and spindles, the due understanding of which would seem to be a matter of almost hopeless difficulty. But to him who has studied mechanism in its various aspects, and who has been taught to analyse its movements, the difficulty is only apparent; and in process of time, by an analysis, brief but searching, the whole movements are unravelled, and from the confused and whirling mass order and regularity are deduced. It is our purpose in the present chapter to introduce the reader to this method of mechanical analysis, by which he may be enabled not only to understand the working details of perfect machines, but also to arrange and modify the simple elements of mechanism, considered individually, into the collective forms which may be designed for special purposes.

In fig. 135 is shown a method of CHANGING the DIRECTION OF MOTION.

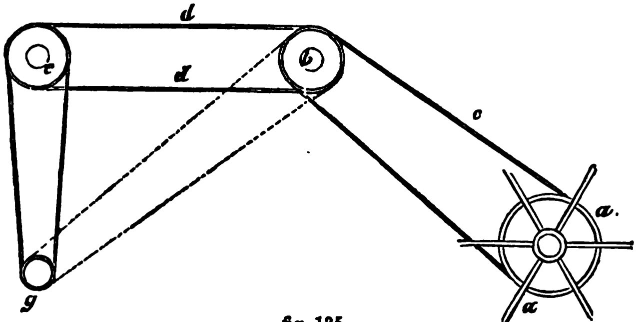


fig. 135.

Thus, the motion is first given to the wheel $a\ a$, as that of a fly-wheel of a *steam-engine; it is first* transmitted to b by the belt c, the pulley e is

moved by the belt *d d* from *b*, and *g* from *e*: the pulley or shaft *g* may be driven by a diagonal belt, as seen by the dotted lines. In fig. 32, motion is communicated from the wheel *a* to *b* by the belt; in this case the movement of both wheels is in the SAME DIRECTION. In some cases it is desirable to give the driven wheel *b* a motion in the REVERSE DIRECTION of the driving wheel *a*. This is effected by crossing the belt, as in fig. 136.

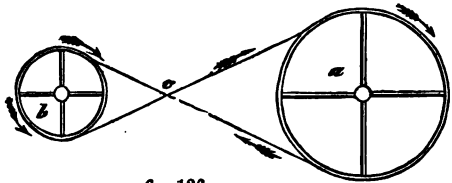


fig. 136.

Where a wheel drives a pinion, they revolve in contrary directions; by the interposition of a third wheel, as *b*, fig. 137, the driven wheel *c* will revolve in the same direction as *a*, the driving wheel. In the contrivance known as the annular wheel, fig. 138, the driving wheel *a* has its motion in the same direction as the driven wheel *b b*.

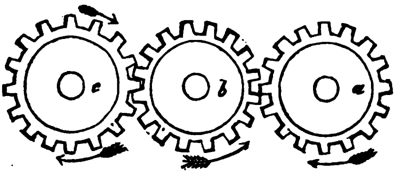


fig. 137.

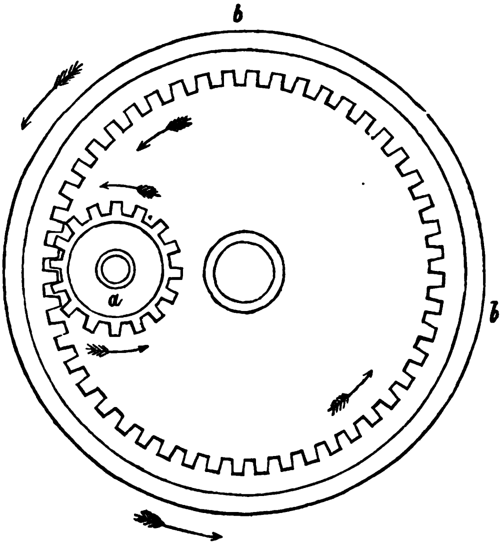


fig. 138.

The RELATIVE VELOCITY of wheels, shafts, &c. may be altered and modified by simple means. Thus, suppose in fig. 31 (p. 30), the large wheel is three times the diameter of the small, then it is evident that the former

will revolve only once, while the latter will revolve three times. Again, in fig. 32 the small pulley revolves faster than the large one just in proportion as it is smaller. Fluted rollers revolving in contact, as $a\ b$, fig. 139, move at the same speed if of the same size; but if b was only half the size of a, it would move twice for a once. In cotton-machinery rollers are much used; fig. 139 will explain one of the many modifications.

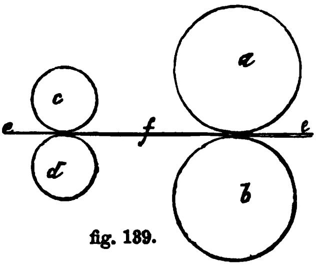


fig. 139.

Suppose a and b to be revolving in contact, and making six revolutions per minute; and $c\ d$ half the size of $a\ b$, consequently revolving twelve times in a minute; let $e\ f\ e$ be fibres of cotton passing through between the rollers $a\ b$, and taken up by $c\ d$; suppose $a\ b$ deliver eighteen inches per minute; as $c\ d$ revolve twice as fast, they are manifestly capable of pulling through thirty-six inches of fibre every minute; but $a\ b$ only deliver eighteen inches in that time; consequently the fibres must either be torn asunder or elongated at f, or somewhere between the two pair of rollers. This is just exactly as designed. The relative velocities of the rollers are so adjusted, that a certain degree of draught is given to the cotton fibres. Simple as this contrivance appears, it is that which has enabled cotton-machinery to be so marvellously quick in its operation; and without which, it may safely be said, the manufacture must have failed to reach the height of its present comparative perfection. In toothed wheels, the relative velocity of each is modified or changed by merely altering the number of teeth and diameter of wheel. Thus in fig. 140, the velocity of the pinion a is nearly three times greater than that of b; by making a the driving wheel, b revolves only once for a thrice. This is the method employed in cranes for lifting heavy goods: a is turned by means of a handle or winch attached to its axis; the object being to give the wheel b, on the axis of which the barrel for winding the chain or rope is fixed, a slow motion.

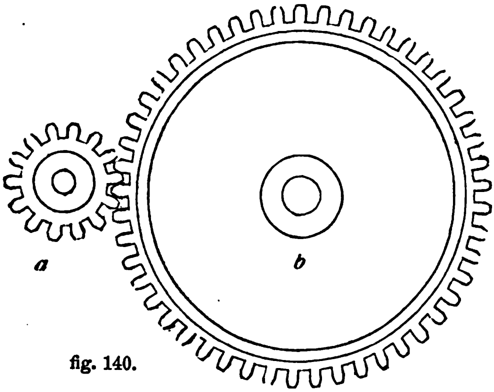


fig. 140.

Where a VARYING velocity is required to be given to shafts, &c., the contrivance known as the "speed-pulley" is used. Suppose $a\ a$, fig. 141, to be the driving shaft, communicating motion to $a'\ a'$ by means of pulleys and belts; drums of different diameters, as b', c', d', are fixed on $a\ a$, as also on $a'\ a'$, as at $b\ c\ d$; the small one d is placed opposite the large one d''; by shifting the belts it is obvious that the ratio of the speed of the two shafts may be altered as desired: this form is used principally in

lathes. Another form is used, represented in fig. 142, being two conical drums placed conversely; *a a* being the drum on the driving shaft *b b*, *a′ a*,

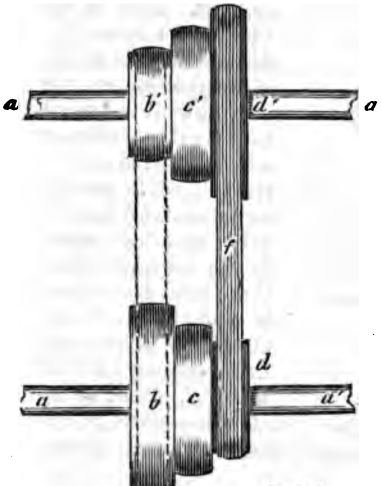


fig. 141.

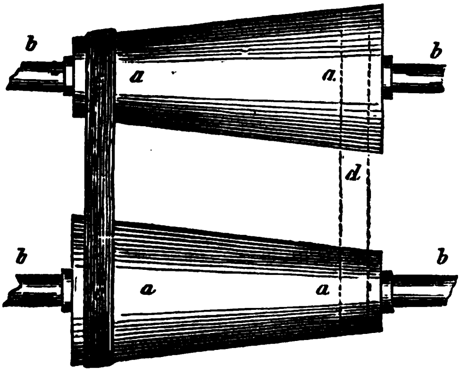


fig. 142.

being that on the driven *b′ b′*; by moving the belt *c* the relative velocities of the two shafts may be changed: this modification is used in the cotton-machine known as the "roving frame."

The fusee of a watch is a modification of this contrivance. As is well known, the moving power is supplied by a spring wound up within a cylindrical box or barrel *c c*, fig. 143, revolving on an axis in the plate *b b*. On first starting after being wound up, the spring exerting its greatest force, it would have a tendency to make the watch go very fast, this gradually decreasing as it got unwound. To make its effect on the mechanism equal throughout, a chain *d* is employed to give motion to a conical drum *a*, on the surface of which a spiral path, or groove, is cut: the two are so arranged, that on first starting the chain acts on the small end of the drum, thus exerting a slight leverage; but as the spring uncoils and winds up the chain on its surface, it acts on the larger end of the drum, thus exerting greater leverage. This mechanism thus introduces an equal movement of the fusee *a*, compensating for the unequal one of the barrel containing the spring (see p. 47). The velocity of the shaft *d* is made to vary as required: a wheel *a a*, fig. 144, supported on the vertical shaft *b*, gives motion to the wheel c, the natural roughness of the surfaces creating sufficient hold between them; the shaft d.

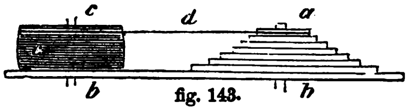


fig. 143.

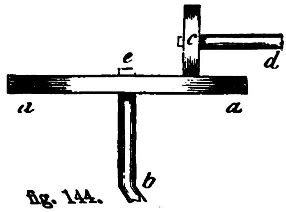


fig. 144.

is capable of being moved laterally by means of a screw; the nearer *c* is placed to the centre *e* of the wheel *a a*, the slower is its motion, and *vice versa.*

Two DIFFERENT MOTIONS can be given by the revolution of one wheel or shaft. Thus, in fig. 145, let *a a* be a cylinder revolving in an inclined position on the bearing *c*; it is desired to make this revolve at a slow speed in one direction, while the internal shaft *b b* is to revolve at a high speed in the contrary direction; a bevil wheel, *e e*, is made to revolve by the handle *m*; it works into a slightly bevilled wheel *d*, placed at the end of the shaft *b b*; the other end of *e* works into the face-wheel *f*; the two motions are thus effected: as thus arranged, the mechanism is that used in a patent "rice-cleaning machine."

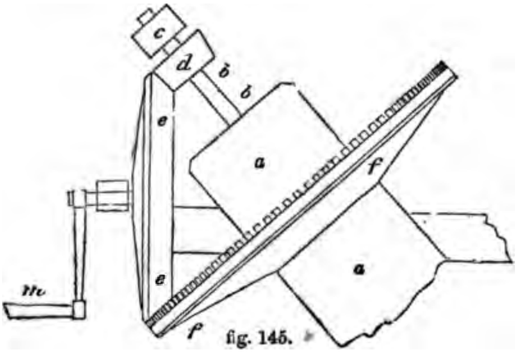


fig. 145.

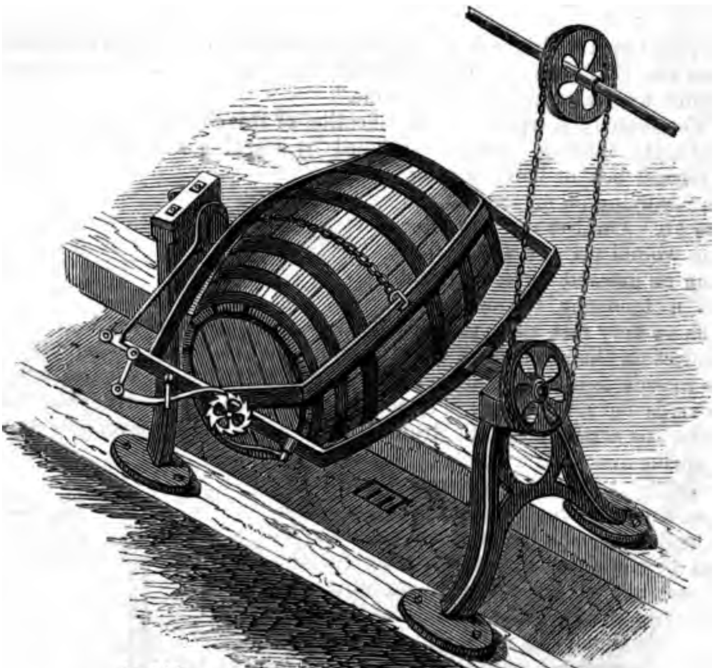


fig. 146.

In the patent "cask-cleaning machine" (fig. 146) two motions are ob-

tained. Each cask is placed in an iron frame or cradle, which revolves within another cradle; while the outer frame makes one revolution in the direction of its length, the inner cradle revolves at right angles to the outer; the revolutions of the inner cradle are regulated by an eccentric placed on the shaft, actuating a lever and ratchet fixed on its axis; the inner frame makes one revolution for every twenty of the outer. A chain of a peculiar construction is attached to a plug placed in the bung-hole; and by the double action above described, this traverses the whole of the interior surface of the cask.

A VARYING motion is produced in a patent flax-machine. To effect a certain purpose, the two rollers *a a*, fig. 147, are required to advance and recede from each other. This desideratum is thus obtained. The bearings *b b*, on which the rollers revolve, are made so as to slide easily on slotted bars *c c*; a cross-head *e*, which has a vertical reciprocating, or up-and-down motion given to it by the rod *f*, has two links *g g*, fastened at each end; these links are passed round the ends *d d* of the shafts of the rollers *a a*; the links *g* are made to incline as in the sketch. Suppose *f* to be moved upwards, the cross-head *e* and links *g g* partake of the motion; as the space between the links thus increases, the bearings *b b* slide outwards on *c c*. The fullest extent they can be separated is clearly equal to the extent between the centres of the links at their widest part; on the rod *f* descending, the space between the centres of the links decreases, and the bearings *b b* move inwards and approach each other.

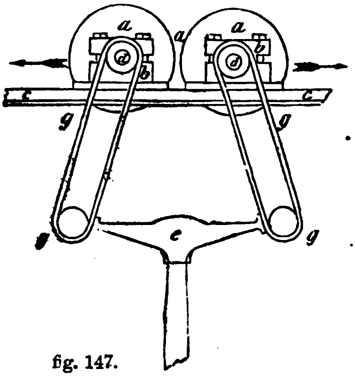


fig. 147.

In the "warp-mill" used in cotton-factories, the yarn is laid regularly on the mill by a varying motion thus: *a a a a*, fig. 148, is the frame on which the yarn is to be regularly laid; it is made to revolve by a strap

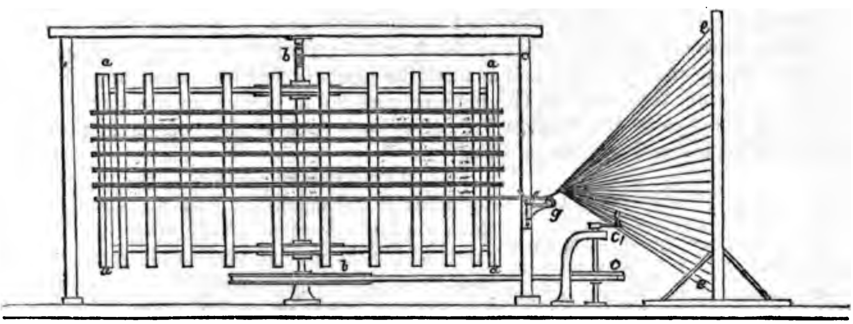


fig. 148.

passing round the pulleys *b* and *c*, the latter being worked by the crank-handle *c′*; the full bobbins containing the yarn are made to revolve hori-

zontally on wires or rods in the frame *e e*; the threads pass from each through eye-holes in *g*; this moves up and down on the vertical part to which it is attached; a cord passing round the frame spindle *b*, and over pulleys to *g*, by the revolution of the spindle *b* gives the required up-and-down motion of *g*. The yarn from the rollers *h h*, of a cotton-slubbing frame, fig. 149, is laid evenly on the bobbins *b b*, which revolve on the

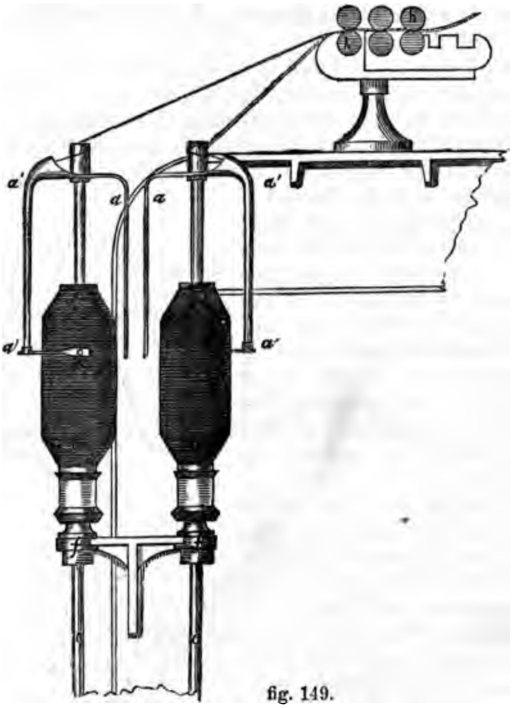


fig. 149.

spindles *c c*; the yarn is delivered to the bobbins at *x*, passing from the rollers through the hollow leg of the flyer *á á*; the bobbins rest loosely on the copping-rail *f f*; this rail is made to rise and fall by means of racks and a pinion, thus making the bobbins pass up and down on the spindles *c c*, and opposite the "finger" *x*; thus each part of the bobbin is presented to the delivery-finger at *x*.

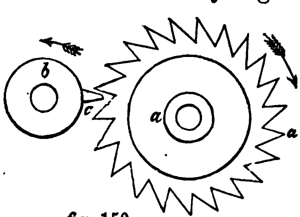


fig. 150.

An INTERMITTENT motion is frequently desiderated in machines; in fig. 150 we show a simple method of effecting this: a ratchet *a a* is moved one tooth forward each time the wheel *b* revolves, the projecting tooth *c* catching one of those of the ratchet. It is obvious that by arranging the relative velocity and size of the wheel and ratchet, and the number of teeth, the ratchet *a a* may make a certain number of revolutions in any desired time.

An intermittent motion required in the patent flax-heckling machine is produced as follows: a shaft attached to the ratchet-wheel *h h*, fig. 151, is required to revolve only a certain portion at stated intervals; a cam *a* gives motion to a lever *b*, the centre of motion of which is at *c*; at the end *d* a vertical rod *e* is connected at its upper end to the bell-crank lever *f g i*, the centre of which, *g*, is firmly secured to the ratchet-wheel *h h*; there is a catch placed at *i*, which takes hold of the projections of the wheel *h h*; as the lever *b* rises, the rod *e* causes *f* to rise; this makes the catch *i* slide over the surface of each tooth on the wheel *h h*; on the lever *b* falling, *f* is pulled downwards, and the catch at *i* taking hold of the projection, causes the wheel *h h* and its shaft to move a certain portion of its revolution. An intermittent motion is often used in looms for weaving cloth by power. As the cloth is woven, it is wound upon a roller called a "cloth-beam;" in order that the cloth be taken up by this beam just as fast as it is produced, and no faster, it is necessary to make it revolve at a certain speed: this is effected by mechanism somewhat resembling the above contrivance. A cam, or wiper, placed on the central shaft of the loom gives an alternating motion to a lever; this acts by the intervention of another lever, furnished with a catch at its upper end, upon a faced ratchet-wheel, somewhat like the crown-wheel of a watch; the shaft of the ratchet-wheel has an endless screw at one end, working into a toothed wheel placed on the end of the cloth-beam. By this mechanism the cloth-beam is turned round at certain intervals, depending on the velocity of the shaft on which the cam is placed, which moves the levers; and as this central shaft is connected with the cloth-producing motions of the loom, it is evident that the motion of the cloth-beam will be in direct ratio to the speed at which the cloth is produced. In practice, however, a slight variation exists; to counteract which, various ingenious devices have been brought out. Another simple method of giving an intermittent motion may here be noticed. In a machine called the "flax-heckling machine" it is necessary that a contrivance called a "holder" should be moved along bars placed above the main cylinder at certain intervals. In fig. 152 let *a a* be the holder, and *ó* the suspended flax; *b b* the bars on which *a a* is supported; it is desired to move *a a* along *b b* at certain stated intervals: let *c c* be a light bar, parallel to *b b*, but capable of lateral movement in two directions, as shown by the arrows; from this bar let fingers *d* be suspended at intervals, and movable on joints, but provided with catches, as *m*, which will prevent the fingers moving in any other direction but one; on moving *c c* towards the left, the finger will slide over the top of *a a*, as seen by the dotted lines at *e*; but on reaching a certain part it will drop perpendicularly at the end of *a a*; the motion of the bar *c c* is now changed, and moving towards the right, the finger *d* prevented from

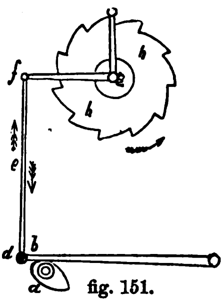


fig. 151.

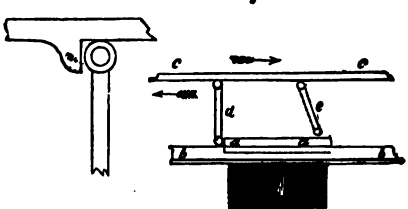


fig. 152.

moving in the wrong direction by the catch *m*; the holder *a a* is thus necessarily moved along *b b*. By modifying the speed of the bar *c c*, and the length of its movement right and left, and the number and distance from each other of the fingers, the holders may be moved along at any desired ratio.

An ALTERNATING motion is obtained by the revolution of a crank, connected with a "doffer knife" *c c*, by the side rods *b b*, fig. 153 (the crank is not shown), of the "cotton-carding engine," the doffing cylinder of which is shown at *a a*: the cotton filaments caught on the card-teeth on the surface of *a a* are stripped off by the doffer knife *c c* (which has a quick up-and-down motion), in the shape of a beautiful light fleece *d d*; this is contracted and passed through a trumpet-mouthed orifice *e*, and passing through rollers *f*, is placed in a tin can below *g*. The alternating motion of the threads in a loom is obtained by pressing alternately on heddles *G G*, fig. 154. In weaving, one-half of the horizontally stretched threads or yarns *C C*, are required to be lifted up; each alternate thread is passed through between the loops of the threads of the healds *D D*, these being suspended from the top of the frame, and attached at the foot to the heddles; on moving each of these alternately, thereby depressing its heddles, it is evident that the threads passing through the loops will be moved out of the line of the others.

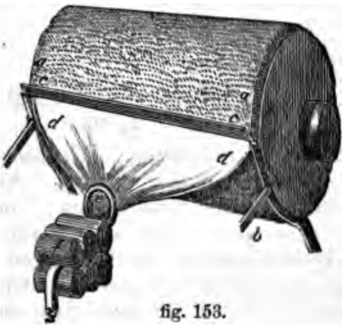


fig. 153.

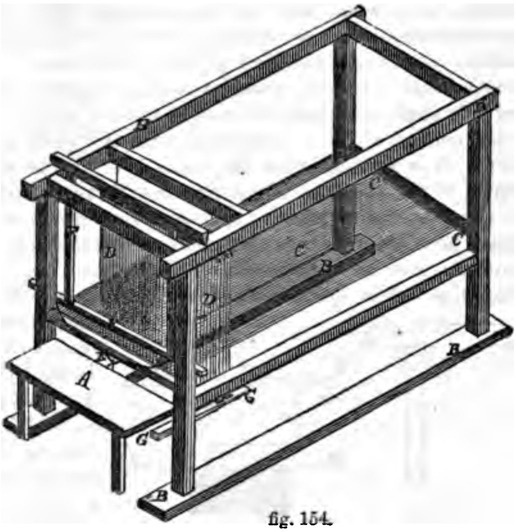


fig. 154.

In fig. 155 we illustrate the mechanism known as the "mangle-wheel motion," by which an alternating movement is given to a pulley *a a a*, imparting motion to the driving belt *b c*, first in one direction, as shown by the arrow *b*, and then in the opposite as at *c*. The pulley *a a a* has a double circular rack, *d d d*, the teeth of which are continued all round, as shown by the dotted lines *e e f*. The stud on which the pinion *h* revolves is allowed to move in the slot *i i*. Suppose the pinion *h* to have a continuous motion imparted to it in the direction of the arrow *k*; in the position in which it is shown in the drawing it would cause the circular rack *d* to move in the direction of the arrow *l*, but on

the point g of the rack coming up to the teeth of the pinion h, the stud of the pinion would be forced to slide along the slot i i, till the pinion began to engage with the inner teeth of the rack, when the rack would be made to move in the direction of the arrow m, and the belt e would move in the direction of the arrow c. But when the rack would be brought round till the point f come in contact with the pinion, the pinion would slide in the slot i i till it engaged the outside teeth of the rack, which would then move in the direction of the arrow l as before.

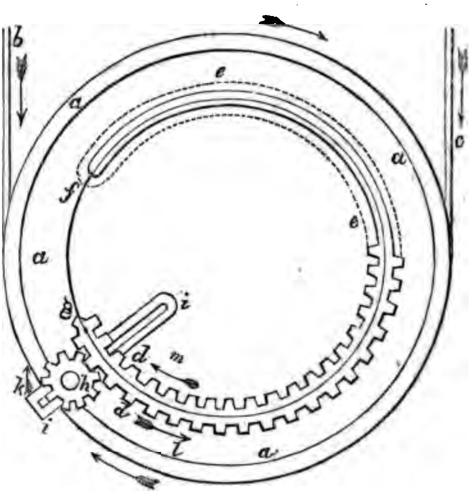


fig. 155.

A CIRCULAR MOTION IS CHANGED INTO A RECIPROCATING by what is called the rack and pinion. Thus in fig. 156, a a is the horizontal rack, the upper part of which is provided with teeth; the teeth of the pinion b work into these, and cause the bar to be moved horizontally; by turning the engraving, so as to make a a vertical, the method of making the circular motion of b impart a vertical one to a a is at once obvious. By giving the motion in the first place to the rack, it is clear that the wheel b will have a circular motion.

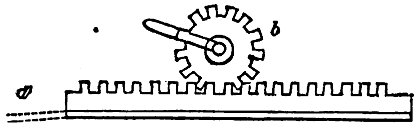


fig. 156.

AN INTERMITTENT CIRCULAR MOTION is made to impart an INTERMITTENT HORIZONTAL one as follows: Suppose a a, figs. 157 and 158, to be part of the holder-frame of a flax-heckling machine; on each side of this, vertical racks f f are placed; small pinions c c, revolving in bearings b b, work into the teeth of these; the shaft of the pinions carries a toothed wheel d in its centre; this works into the teeth of a horizontal rack, this forming part of the finger-bar which moves the holders. On the table a a rising, the pinions c c are made to revolve by coming in contact with the teeth of the racks f f; the wheel d partakes of the motion of c c, and in its turn moves the rack e, and the finger-bar to which it is attached. In this piece of mechanism, the changing of a vertical motion into a circular one is seen by the racks f f moving the pinions c c, and the changing of a circular into a horizontal, by the wheel d moving the rack e.

To change a reciprocating circular motion into a continuous circular motion.—In fig. 63 the beam a a, vibrating on the centre b, affords an exemplification of reciprocating circular motion, the end describing part of a circle. In fig. 69 we have illustrated and described a very common

method of effecting the above change of motion : *d* is the connecting-rod, attached to the end of the reciprocating beam ; *b* is the crank, fastened on the end of a shaft at *e* ; the connecting-rod is attached by a movable

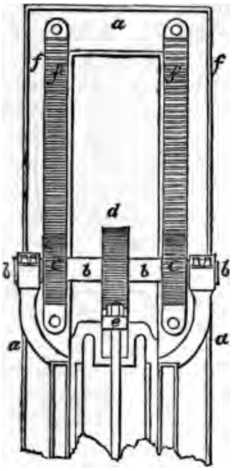


fig. 157.

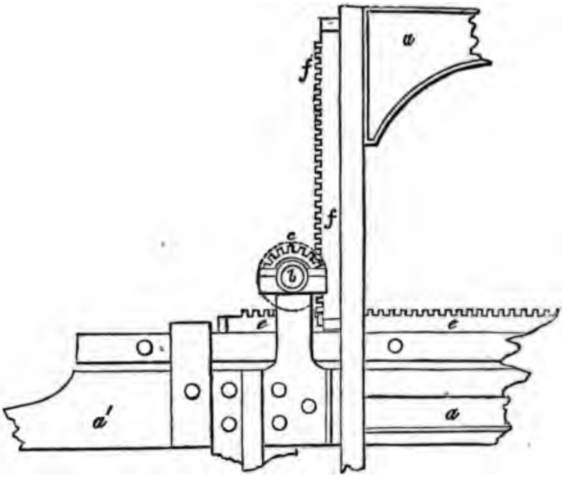


fig. 158.

pin at *c*. In fig. 76 we have given a familiar illustration of this contrivance in the foot-board, crank, and wheel of the knife-grinder's machine : *a a* corresponds to half of the reciprocating beam ; *b* is the rod connecting it

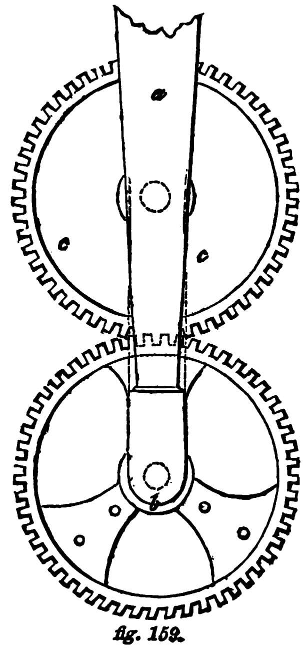


fig. 159.

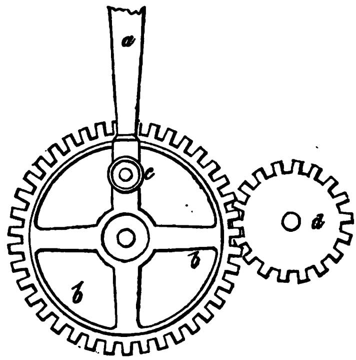


fig. 160.

with the crank. The motion used by Watt to change the motion of the beam of his steam-engines to a circular one is another contrivance which may be here noticed : it is known as the "sun and planet motion." The toothed wheel *c c*, fig. 159, is fixed to the end of the fly-wheel shaft, which is to have a continuous circular motion. Another toothed wheel *b*, of equal diameter with *c c*, is attached at its centre to the end of the connecting-rod *a*, and is capable of revolving on its centre. The two wheels are kept in gear by means of a slotted link. An up-and-down stroke of the connecting-rod, or one complete oscillation of the beam, will have made one revolution round the centre of the wheel *c c* ; but both wheels being fixed to their centres, the wheel *b* will revolve round *c c*, each tooth coming in contact with those of *c c*. If the two wheels are of equal sizes, the wheel *c c* will make two revolutions for each time the wheel *b* travels round its circumference. Another method of effecting the change of motion under consideration is illustrated in fig. 160 : let *d* be a toothed wheel fixed on the end of the revolving shaft, and *b* one twice the size gearing into it ; let the end of the connecting-rod *a* be attached by a movable joint at *c* to one of the arms of *b* ; then the reciprocating circular motion of the beam to the end of which the rod *a* is attached is changed into a continuous circular one at *c*. In fig. 161 we give a method of changing a vibrating motion of a beam *g g* into a rotary one of the fly-wheel *n n*. Two sets of teeth, *l* and *m*, are formed on the segment, which take into two pinions placed loosely on the fly-wheel shaft, the teeth being in different planes for that object. The pinions have spring-palls attached, which take into the teeth of ratchet-wheels fixed to the shaft. The teeth of these ratchets are set in opposite directions; so that while one pinion is transmitting the motion of *g g* to the main shaft, the other pinion

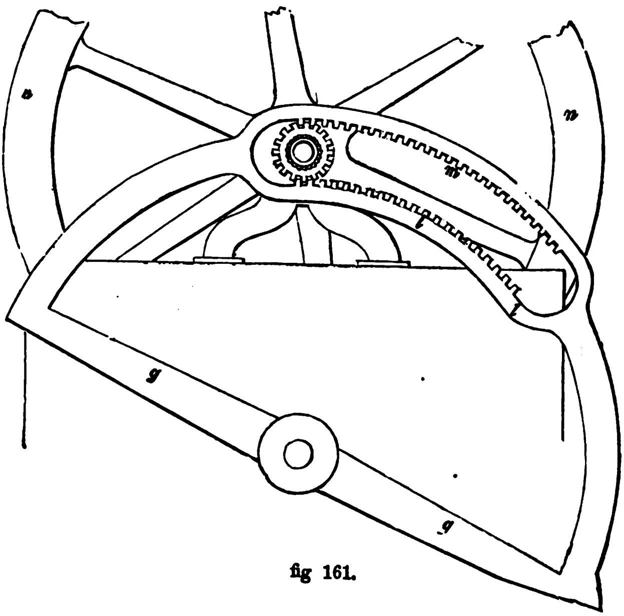


fig 161.

is revolving on the shaft in the reverse direction, and its pall slipping backwards over the teeth of its appropriate ratchet-wheel.

To change a reciprocating rectilinear motion into a circular one.—Let *a a*, fig. 162, be the piston-rod of a steam-engine, moving horizontally in

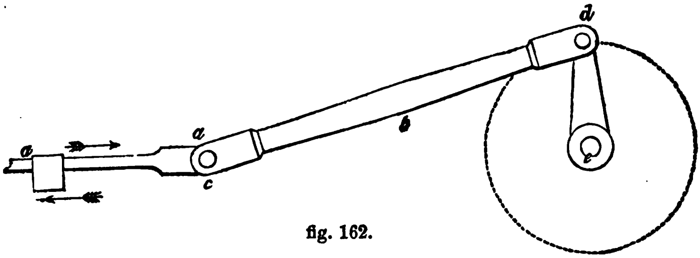


fig. 162.

guides, backwards and forwards, as shown by the arrows; a connecting-rod *b*, moving on the centre *c*, and attached to the crank-pin at *d*, will give the shaft *e*, to which the crank is fixed, a continuous circular motion. This is the movement used in steam-engines where the cylinder is laid *horizontally*. In small steam-engines, where the cylinder is vertical, and

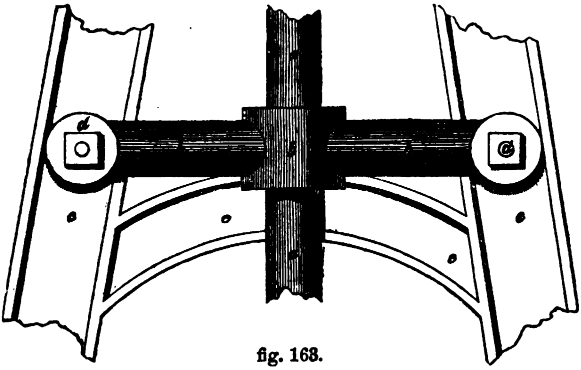


fig. 163.

the crank above the cylinder, the piston-rod moves vertically up and down in a guide attached to the framing of the engine. Thus, in fig. 163, *c c c* is part of the framing of the engine, or standard, on the top of which, in a suitable bearing, the crank-shaft revolves; *a a* is the piston-rod, which

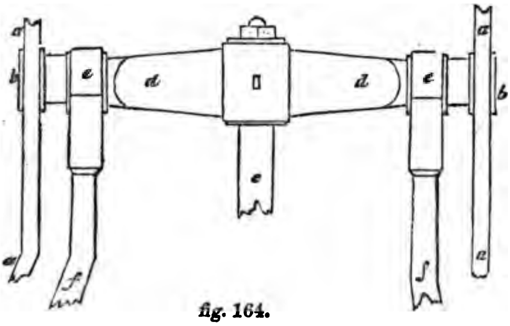


fig. 164.

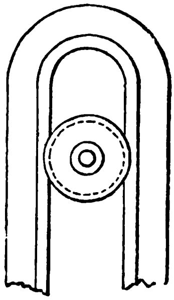


fig. 165.

moves up and down, sliding in the guide *b b*, which is attached to the standard by bolts *d d*; the connecting-rod is attached to the end of the piston-rod, and the other to the crank-pin. This modification is that used in the form of high-pressure engine known as the "crank overhead." Another modification is given in fig. 164. The piston-rod *c* is provided with a cross-head *d d*, the ends of which are provided with circular parts sliding within a slot in the side framing *a a*, a side view of which is shown in fig. 165. The connecting-rods *e f*, *e f*, are attached by straps and brasses to journals made in the cross-head *d d*, the other ends to two cranks placed beneath the cylinder, which stands on a frame.

The method employed by Dr. Cartwright for changing the up-and-down motion of the piston-rod of his steam-engine into a continuous circular one, is shown in fig. 166. The cross-head *d* of the piston-rod *a* has two connecting-rods *m m*, jointed at *c c*, and attached to two cranks *c′ c′* fixed to the axes of two toothed wheels. While the piston *a* makes an up-and-down stroke, the large wheels make a complete revolution: the rate of motion of the small pinion fixed in the main shaft depends upon the number of teeth in *n* compared with that in *o*.

To change a continuous circular motion into a reciprocating rectilineal one.—A simple method of doing this is shown in fig. 92, where *a* continually revolving, brings the wipers *b b* in contact with the projection *c*, placed on the vertical beam *d*. This is the motion used in mills where stampers are employed. Again, suppose *c*, fig. 167, to be a stamp or punch, moving vertically in a fixed guide *d d*; by attaching a connecting-rod to the end *m*, and its other extremity to a pin *n*, placed in the face of

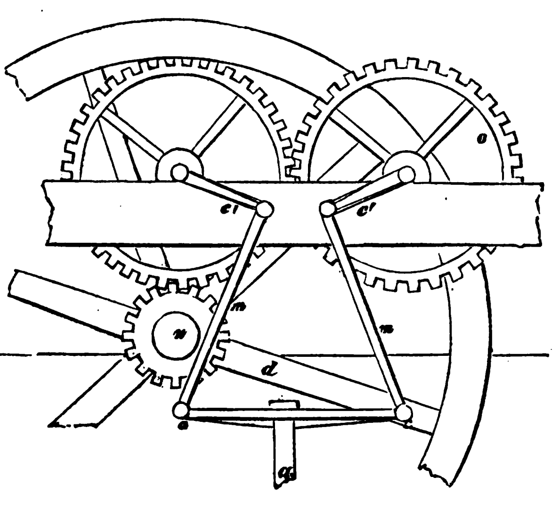


fig. 166.

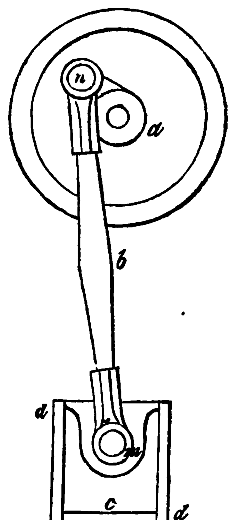


fig. 167.

the wheel *a*, at a certain distance from its centre, the stamp or punch *c* will have an alternate movement up and down, while that of *a* is a continuous circular one.

The continuous circular motion of the cam *a a*, fig. 168, revolving on its centre *b*, gives motion to the lever c, the centre of movement of which

is at *d*; and this, again, a vertical reciprocating movement to the rod *f*. This is the movement used in a flax-heckling machine, to give the holder-table an up-and-down motion. The small wheel *e* serves to reduce the

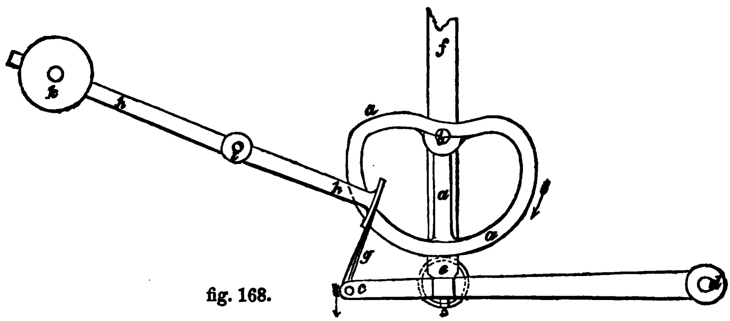


fig. 168.

friction between it and the revolving cam *a a* (see fig. 51, p. 43). The cam is only used to *pull down* the table, it being raised by the lever *h h*, moving on the centre *k*, a heavy counterpoise being at one end; the other end of the lever being attached to the end *c* of the lever *c d* by the link or strap *g*. In fig. 91 the continuous circular motion of the cam *c c* gives a vertical reciprocating one to the rod *d e*. The parts of mechanism used in clock and watch machinery, known as "escapements," are employed to convert a continuous circular motion into a reciprocating one. The continuous circular motion of the cam *b b*, fig. 169, revolving on the centre *a*, gives reciprocating motion to the rod *g*; the edge of the cam works in contact with the friction-wheel *c*, attached to the end *d* of the bell-crank lever *d e f*, vibrating on the centre *e*; a counter-weight *h* gives regularity to the motion. This contrivance is used in the "expansion-gear" of marine engines.

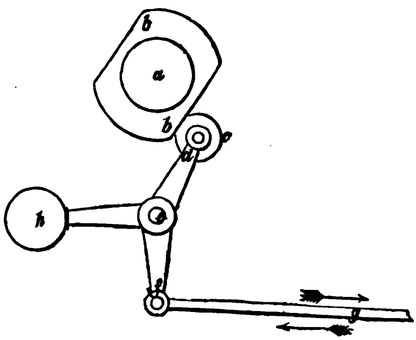


fig. 169.

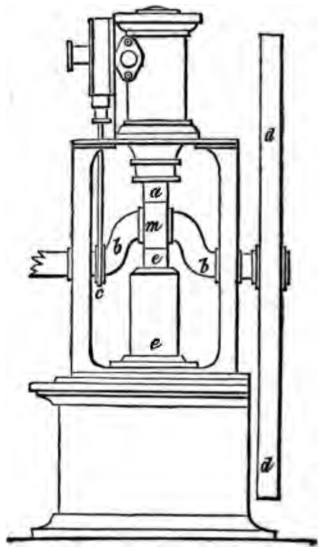


fig. 170.

In the "steam-pump," an elevation of which is shown in fig. 170, the reciprocating motion of the piston-rod *a* gives a rotatory motion to the crank *b b*, fly-wheel *d d*, and eccentric *c*: by the movement of the crank in a longitudinal, horizontal, slotted cross-head *m*, the reciprocating motion of the pump-rod *e* is obtained; by the movement of the piston-rod *a*, the circular motion of the fly-wheel is obtained, applicable to driving machinery; while at the same time the necessary motion of the pump-rod is derived.

If the rack in fig. 156 had only a few teeth on its face, and the pinion *b* with teeth only on half of its circumference, then the continuous circular motion of *b* would give a reciprocating up-and-down motion to the beam on which the rack might be fastened: in this case the rack and beam are supposed to be vertical. On the teeth of *b* catching those of the rack, the beam would be lifted up; but on the toothless portion of *b* presenting itself, the beam would fall, ready to be moved upon the toothed portion of *b* again coming round. If the rack were horizontal, as soon as the teeth of *b* passed round, the rack might be pulled back again by a weight and cord passing over pulleys. In this case the power of *b* would be exerted in moving the rack and beam, and also the weight.

To change a continuous circular motion into a reciprocating circular one.—The contrivance usually adopted for this purpose is that known as the "eccentric." This is merely a circular disc of metal firmly fastened on a revolving shaft; instead, however, of the disc being fixed at its true centre on the shaft, its centre of motion is placed at some distance from

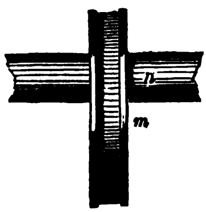


fig. 171.

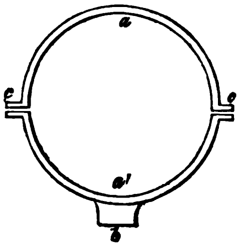


fig. 172.

fig. 173.

it. Thus, suppose fig. 171 to represent the circular disc, the true centre of which is at *m*, the centre of motion is placed at *n*. The edge of the disc or circumference is not plain, but is turned so as to have projections at each side, thus forming a kind of groove. This groove admits of the eccentric rings or hoops *a a′*, fig. 172, being passed round: the rings are made in two halves, and secured, after being passed round the disc, by bolts at the projecting snugs *c c*; the eccentric-rod is generally screwed into the part *b*. A form of eccentric with hoop and rod is shown in fig. 173, where *a b b* is the eccentric disc, its true centre being at *a*, its centre of motion at *e*; the rings *c c* are secured by the bolts *d d*, the rod *f* is connected to the bell-crank *h g* at *g*; the centre of vibration is at *h*; the end *i* describes a portion of a circle; a rod jointed at *i* will have a reciprocating motion; the disc *a* revolves easily within the rings *c c*, which are kept well lubricated to reduce the friction: the ring and rod *f* thus partake of the motion of the disc, and an alternate reciprocating motion of the rod *f* is produced.

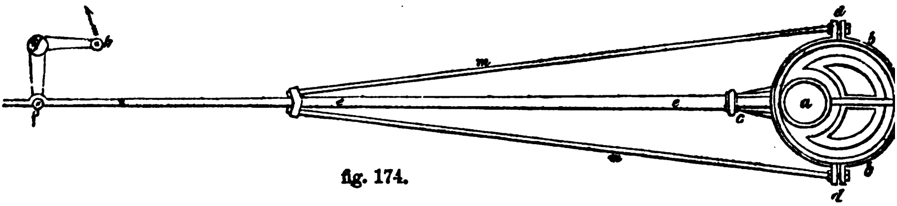


fig. 174.

We give in fig. 174 a form of eccentric gear adopted in large steam-engines: *a* is the centre of motion, *b b* the rings, bolted together at *d d*; *c e e* the rod, strengthened by lateral stays *m m*; *f* the pin of the bell-crank vibrating at *g*; a vertical rod jointed at the other pin *h* will have a reciprocating motion. In fig. 175 an enlarged view is given of that

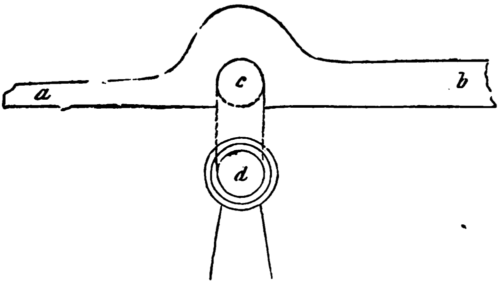


fig. 175.

part of the eccentric-rod which is attached to the crank-pin: a slot with circular end *c* passes over the pin *d* of the crank; when the motion of the eccentric-rod *b* is not required to give motion to the lever *d*, the attendant takes hold of the end *a* of the connecting-rod, and lifts it off the crank-pin; it is then allowed to slide along a portion of the rod *b* near *a*, or the end *a* is tied to a rope attached to any convenient part. Another method of converting a continuous circular motion into a reciprocating circular one is shown at fig. 176: a wheel *m g* has a crank or lever *h* fixed to the end of its shaft; a connecting-rod *i* is attached by

a joint at *k* to a trumpet-mouthed deliverer *d d*, vibrating at *e* on the standard *f*: the part *d d* has a circular reciprocating motion, as seen by

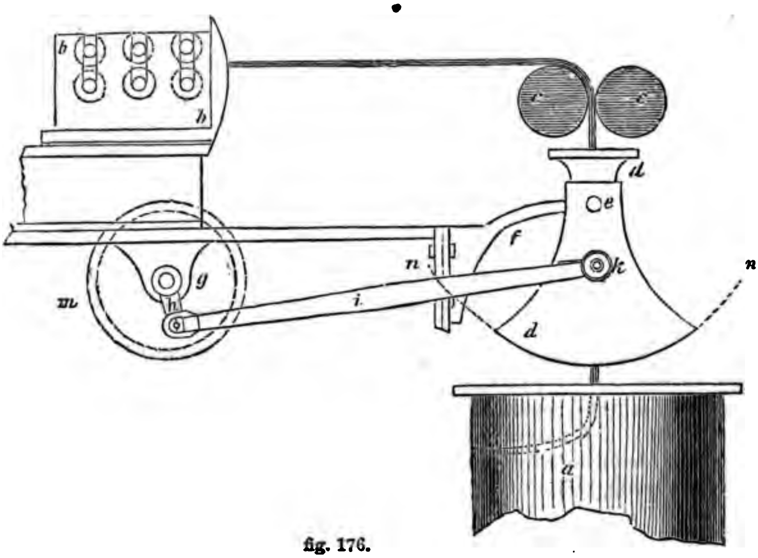


fig. 176.

the dotted line *n n*. The object of this contrivance is to deliver the long "sliver" or riband of cotton fibres passing through the rollers *b b*, *c c*, to the tin can, part of which is shown at *a*, in a regular layer.

To change a reciprocating circular motion into a reciprocating rectilinear one.—This change is seen exemplified in beams of steam-engines, where, as already stated, the end of the beam *a*, in fig. 63, moving in a portion of a circle, communicates a reciprocating rectilinear motion to the piston-rod *d*. In Newcomen and Watt's single-acting steam-engine, where the beam was only pulled down by the pressure of the atmosphere acting on its piston, the weight of pump-gear at the other end raising it again, the means adopted for the straight up-and-down motion of the piston-rod, while the end of the beam moved in a circle, was very simple: we show it in fig. 177. To the top of the piston-rod *d* a chain *c* was attached; this passed over the circular end *b b* of the beam *a a*, and was fastened to the upper end. The sector *b b* was described from *m*, the centre of the beam; on the beam oscillating, the chain coiled and uncoiled on the sector, the line of the piston-rod forming a tangent to the arc *b b*. This contrivance was only available where the piston exercised a pulling motion; but where the impulse of steam was given not only to depress but to raise the piston, another contrivance was obviously necessary. The genius of Watt, the great improver of the steam-engine, was equal to the difficulty of the task; and the beautiful and philosophical mechanism known as the "parallel motion" was the result of his attention to the subject. The subjoined diagram illustrates the motion. Let *a b*, fig. 178, be half of the working beam, vibrating on the centre *a*; let *c* be a point half-way between *a* and *b*; a rod *d m*, called the "radius-bar," equal in length to *a c* or *c b*, is fixed with a movable

joint to a point at *m*, and at the other to the end of a link *c d*, movable on pins at *c* and *d*. Suppose the beam *a b* to oscillate on its axis *a*,

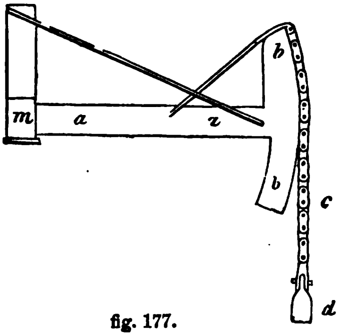


fig. 177.

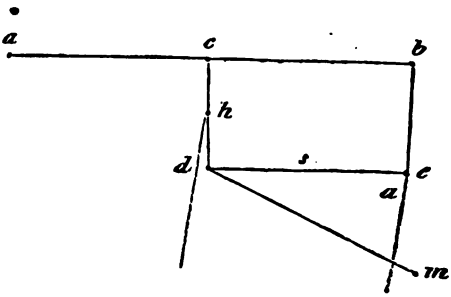


fig. 178.

the point *c* will describe a portion of a circle of which *a* is the centre, and at the same time the point *d* will move in a circle of which the centre is *m*; the result of these movements is, that the middle point *h* of the link *c d* moves in a straight line,—at all events, so nearly that the deviation in practice is of no moment. This movement, so far described, gives an explanation of the principle; but the movement

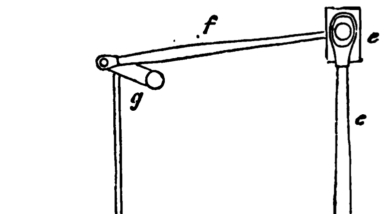


fig. 179.

as carried out in practice is made complete by the following additions: Another link *b e*, equal in length to *c d*, is attached at *b* to the end of the beam by a movable joint or stud; "a parallel bar" *s*, parallel to the beam *a b*, joins *c d* and *e b* by movable joints at *d* and *e*; the point *e* will move in a straight vertical line *e b*; the air-pump rod is attached to the point *h*, and the piston-rod to the point *e*. In fig. 63 is shown the method in which the parallel motion of a steam-engine is arranged: where *a a* is the beam; *m* the radius-bar, the fixed centre of which is at *h*; *g* is the parallel bar connecting the links *e f*. The form of parallel motion used in marine engines is given

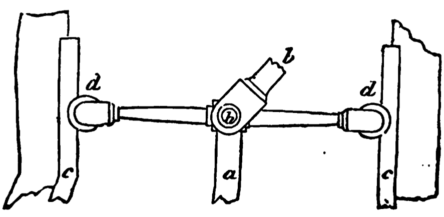


fig. 180.

in fig. 179: where *a b* is the beam, which is placed at the foot of the cylinder and framing; *c c* the side lever, attached to the end of the piston cross-head *e*; *f* the "parallel bar," *g* the "radius bar," *h* a rod connected with the beam and radius-bar. In high pressure steam-engines, the piston-

rod is made to move in a straight line by pulleys attached at each end of the piston cross-head, and sliding between two vertical guides: thus, in fig. 180, *a* is the piston-rod, *d* the pulleys, *c* the guides, *b* the connecting-rod. The movement known as "White's parallel motion" is also available for this purpose. In fig. 181, let *a a* be a large annular toothed wheel fixed at the points *b b* to a framing; let *e e* be the piston-rod, *d* the crank-pin, which is fixed to the circumference of a small toothed wheel *c c*; the vertical movement of the piston-rod causes the wheel *a a* to roll within the inner circumference of the annular wheel *a a a*: if the diameter of the wheel *c c* is one-half of that of the wheel *a a*, or equal to its radius, then the point *d* will describe a straight line in the direction *d e*; if the proportions are different from the above, the point *d* will generally describe a curve known as the hypocycloid.

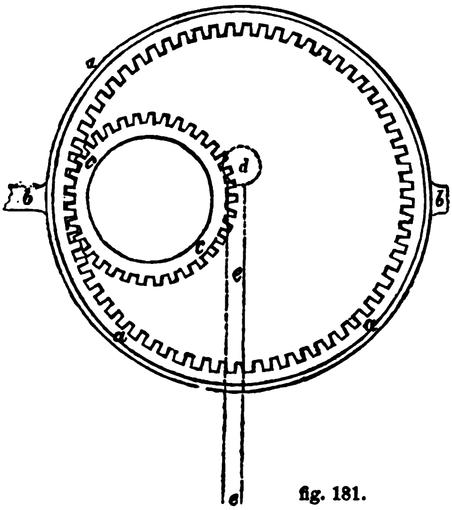


fig. 181.

A recently patented "parallel motion," applicable to horizontal steam-engines, is given in fig. 182. Let *a a* be the piston-rod; *c c* part of a vertical frame, having a slot *d*, near the top; at the joint *f*, to which the connecting-rod *b* is attached, a link is placed, the stud at the other end, *e*, of which moves up and down the slot *d*; at *h'* another lever, *h*, is attached, oscillating on the centre *g*. A vibrating motion given to the pinion *b*, fig. 156, will change its circular reciprocating motion to a reciprocating rectilinear one, by making the rack move up and down.

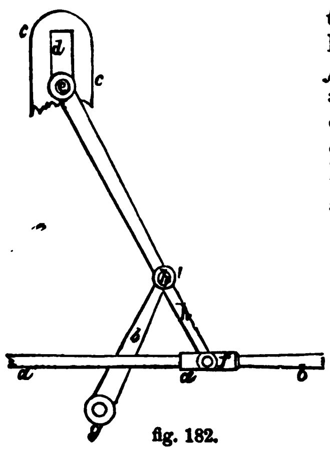


fig. 182.

We have now to notice the contrivances adopted for *regulating* motion. These are generally applied in cases where a movement is not uniform: thus, in the use of a crank, there are certain points where the connecting-rod has no influence in producing circular motion of the shaft to which it is attached. Thus, in fig. 69, if the crank-pin *a* was at a point exactly beneath the centre *e*, it is evident that any force exerted by the connecting-rod would be expended merely in pressing down on the crank-pin and shaft; in like manner, if the point *a* was placed exactly vertically above the centre *e*, the force of the connecting-rod would be only a pull upwards, thus tending to raise the crank-shaft out of its bearings.

These two points are called technically the "dead points," inasmuch as the power communicated to the connecting-rod is inert or useless in giving circular motion to the crank-shaft. To obviate this inconvenience, advantage is taken of the momentum of a heavy body. A large wheel with heavy rim is attached at its centre to the crank-shaft; the momentum acquired by the heavy mass during the period when the full force of the connecting-rod is given out, is sufficient to carry the crank past the "dead points." Thus the alternate motion of the beam is changed, by the intervention of the connecting-rod, crank, and fly-wheel, into a continuous circular one.

In marine and locomotive engines, where no fly-wheel is used, two engines work together, but the cranks are placed at right angles to each other; thus while one crank is at its dead point, the other is receiving the full impulse of the engine. In fig. 183, *a a* is the main crank-shaft, on which the paddles or driving wheels are fixed; *c c* a crank, *d d* a similar one shown in dotted lines, but at right angles to *c c*; that is, the end of it is only seen, as at the double dotted lines at *d*. In Mr. Brunel's "oblique engine," two cylinders are employed to give motion to one crank. The cylinders are inclined to each other at an angle of 60°; thus the framing takes the form of an equilateral triangle, the cylinders rest on the side, and the main shaft works on bearings placed on the apex of the triangle. "The piston-rod is preserved in its rectilineal course by metal rollers running upon guide plates. . . . . When the piston of one of the cylinders is at half-stroke, the piston of the other is at the termination of its stroke or nearly so; and thus the irregularities of the one cylinder

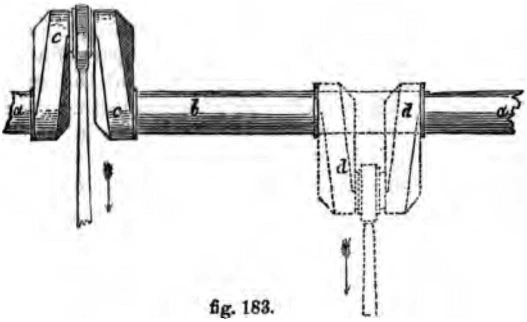


fig. 183.

partly counteract the irregularities of the other." We may here notice the ingenious contrivance adopted by Mr. Buckle, and termed a "pneumatic equaliser." "It acts upon the principle of causing the engine to drag up a piston against the pressure of the atmosphere, when the energy of the moving power is above the average; the power thus consumed being returned to the engine by the atmosphere forcing down the piston, when the energy of the moving power is below the average." The fusee of a watch, described and illustrated in fig. 143, is another method of regulating motion. The "steam-engine governor" is another important regulator. In fig. 184 we give an elevation of this beautiful piece of mechanism: *m m* is a vertical rod revolving in bearings at top and bottom, and put in motion by the pulley *e*; two heavy balls *c c* are fastened to the ends of bent levers *a a a′ a′*, the centre of which is at *b*, these levers

passing through a slot made in the rod *m* at *b*, and secured by a pin passing through both sides of this and the two levers; the levers thus turning on the pin *b* can be made to recede from or be drawn towards each other, like the arms of a pair of pincers; the ends *a′ a′* are attached to small links *n n*, joined to projecting snugs *o o* by small studs or pins; to keep the levers *a a* in their true position, they are made to move within guides *f f*; a stop *d d* is sometimes fastened to the rod *m*, having circular parts cut out at the extremities. When the "governor" is at rest, the balls rest on this stop; on the rod being put in motion by the pulley *e*, the centrifugal force generated causes the balls to fly outwards, thus opening the extent between *a a*, and on the contrary lessening the distance between *a′ a′*; this acting upon the links *n n* causes the projecting snugs and attached ring to slide upwards on the rod *m*; this raises the end of the lever *s s*, depresses the other end and the lever *t t*, thus turning the valve attached to the lever in the steam-pipe *v*. The action thus described takes place whenever the engine revolving too fast, causes the governor-balls to fly out, and shuts in a corresponding degree the valve in the steam-pipe; thus less steam is admitted to the cylinder, the engine necessarily goes slower, the governor revolves at a less speed, the centrifugal force is lessened, the balls fall inwards towards the rod *m*, the ring

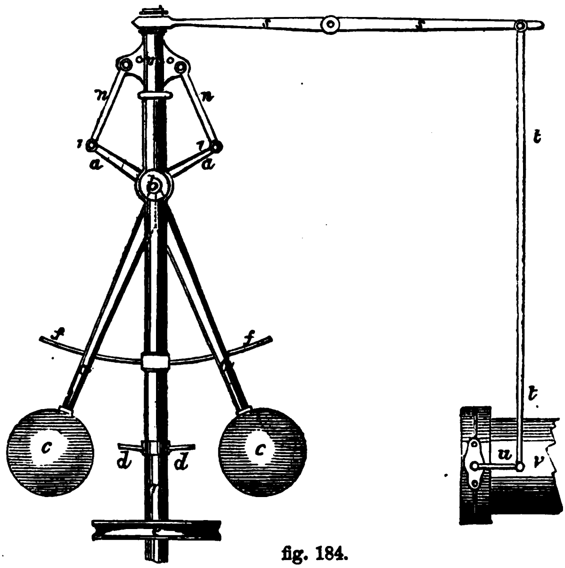


fig. 184.

m o o slides downwards, the lever *t t* is pulled upwards, and more steam is admitted to the cylinder by the opening of the valve; the speed of the engine is again accelerated, again to be checked if too high, and so on; thus keeping the engine at a nearly regular speed. This is one of the beautiful self-acting motions which make machines adjust their various movements almost with creative intelligence, and examples of which will be found in numerous departments of practical machinery. In figs. 185 and 186 we give other forms of governors. A form of governor in

which the inclined plane is a noticeable feature is shown in fig. 187; the vertical spindle *a* turns on an upright bearing, and is made to revolve in the ordinary manner; a disc *b b*, having two circular inclined planes *c c* on the outer edges, is firmly keyed on to the spindle *a*; a cross-head *d d*, having wings or fans *e e* at its extremities, is mounted on the spindle *a*, so as to have a vertical sliding motion up the spindle, and yet capable of revolving; friction pulleys *f f* run on the circular inclined planes or edges of the disc *b b*; a heavy ball *g* is carried by and rests on the cross-head *d*; this keeps the rollers *f f* at the lowest point of the inclined planes; the end of the throttle-valve lever *h* rests upon the top edge of the ball; this moving up or down according to the speed of the engine, shuts or opens the steam-valve, and thus regulates the supply of steam to the cylinder. The operation of the governor is as follows :—on the engine starting, the spindle *a* begins to rotate, and carries round the cross-head *d*; as, however, the speed increases, the resistance of air to the fans *e e* retards its progress; the wheels *f f* consequently raise up the circular inclined plane, and thereby raise the ball *g* and the lever *h*. In order to prevent the wheels being carried over the top of the planes, stop-pieces

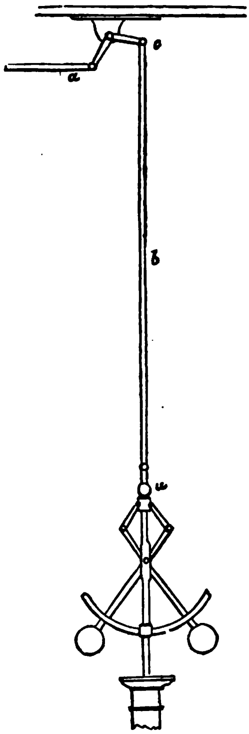


fig. 185.

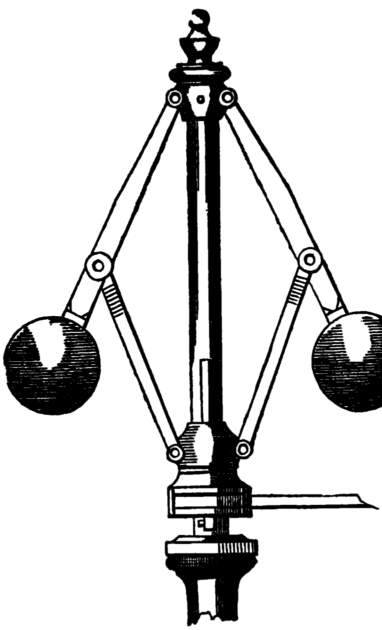


fig. 186.

are there placed, or a lip *j* may be made at the lower end of the ball or weight *g*, and two pins *k k* screwed into the disc *b b*; the pins are fur-

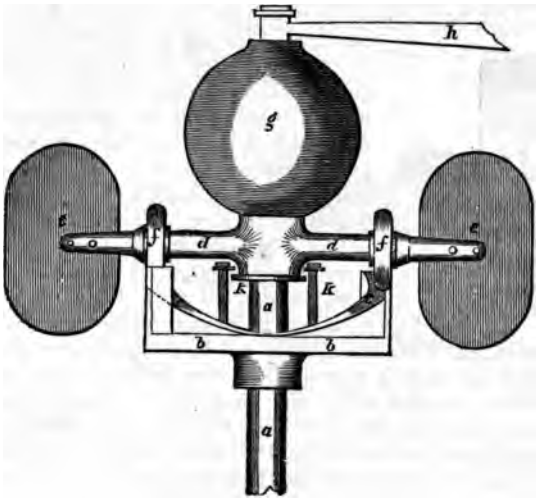


fig. 187.

nished with adjustible buttons, the lip j will come in contact with these, and prevent the wheels from rising too high.

The fly-wheel is a contrivance for accumulating power. Thus the power expended on it is given out while the crank is at its dead points. Buckle's pneumatic equaliser is also another method of accumulating power. A familiar example is met with in the coining and embossing machine: a quick running screw works in a vertical frame; at the lower end a punch or die is placed; beneath this, on a small table, the coin to be struck, or the article to be embossed, is placed; to the upper end of the screw a horizontal lever with long arms is firmly fixed; heavy balls or weights are fixed at the extremities of the lever; the workman whirls the lever and weights rapidly round; the power thus accumulated is given out, in making the screw descend with great force. A modification of this machine is used in making the slits in steel pens, and in punching the eyes of needles.

Engaging and Disengaging of Machinery in Motion.—The couplings, which we have already described, are contrivances by which shafts are not only connected together, but admit of their disconnection when required. It is obvious, however, that this can only be attained when the shafts are at rest. In almost every variety of machine it is necessary to have means whereby the motion from the prime mover can be applied to, and as readily taken from, the actuated machine, and this without stopping or altering the power. In the ingenious and complicated machines employed in the cotton manufacture, it is matter of surprise to the uninitiated how easily the attendants can set one part in motion or stop it; and this without altering in any way the movement of the other parts or of the shafts which communicate the motion from the prime mover.

The simplest, and certainly the most perfect contrivance for engaging

and disengaging machinery, is that termed the "fast-and-loose pulley." Let *a a*, fig. 188, be the shaft to which the motion is to be applied when required, a pulley *b* revolving loosely on the shaft; the pulley *c* is of the same diameter, and is fixed on the shaft by means of a key; when the belt from the driving pulley is running on *b*, the shaft obtains no motion, as the pulley freely revolves on it; but on the belt being shifted by hand to the pulley *c*, the shaft begins to revolve. This movement is almost universally used in machines of every kind. Simple as it appears, it is so effective that the start is effected with little or no shock; a desideratum the value of which may be known, when we state that before its introduction many machines could not be driven by continuous power. In many cases the belt is moved from one pulley to another by hand; this is, however, attended with some danger, as the hand of the operator is sometimes drawn in by the revolving wheel. A method by which the movement is effected is seen in fig. 189, where *d d* are the pulleys, and *a* the belt; the belt moves within the forked end of a lever *b b*, the centre of which is at *c*; by moving this lever from side to side it is obvious that the belt can be easily moved from pulley to pulley. Another method

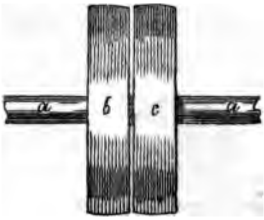


fig 188.

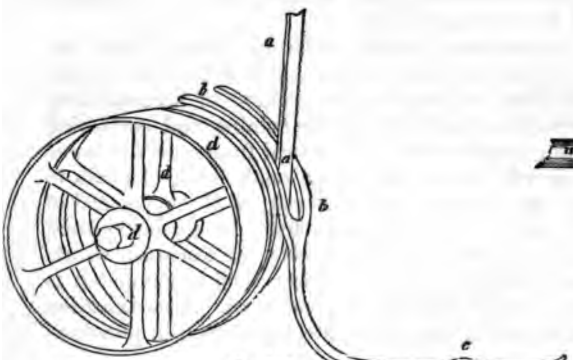


fig. 189.

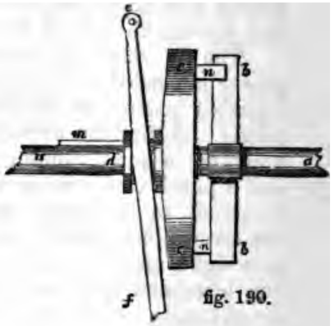


fig. 190.

sometimes used is shown in fig. 190: where *a* is the shaft, *c c* a pulley driven by a belt from the moving power, and revolving freely on the shaft; a clutch *d* is attached to the side of the pulley *c c*; a lever, movable at *e*, lies on the upper side of the clutch; a gland, or cross-piece, *b b* is fixed to the shaft; and cross-pieces *n n* are placed near the circumference of *c c*; by moving the lever *f*, the clutch and pulley are moved along the shaft till the projecting pieces *n n* catch the gland *b b*; the shaft *a a* is thus set in motion. Instead of having the lever, as in fig. 189, movable at a centre *e*, it is sometimes made with a fork, as at *b b*, fig. 191: this embraces the coupling *a*, yet allows it to revolve freely; the centre is at *c*. To avoid the shock in setting shafts too suddenly in motion, various plans are used; the fast-and-loose pulley is a very effective plan, but it is not always convenient to apply it. The following is a method

of effecting the engagement and disengagement of machinery without incurring a shock; it is termed the "friction-cones." On the end of the shaft *a*, fig. 192, a clutch and conical piece are fixed, capable of longitudinal motion on the shaft *a*, but made to revolve with it; this is effected by having a key *e* fixed on the shaft, along which the clutch

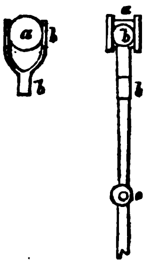


fig. 191.

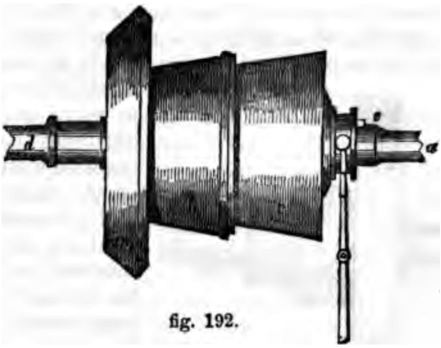


fig. 192.

moves in a slot made in its interior surface. Suppose *m* to be the wheel, fixed on the end of the main shaft *d*, provided with a conical piece *c*, the interior of which receives the exterior cone *b*; by means of the lever the clutch and cone *b* is moved along the shaft; on *b* entering *c*, the friction created is sufficient to move the shaft *d* and wheel *m*. When in gear, they are held by means of a screw or by a weight. On either of the shafts *a* or *d* being stopped, the cones fall out of gear, and the connection is stopped. Another mode adopted for obviating the shock in

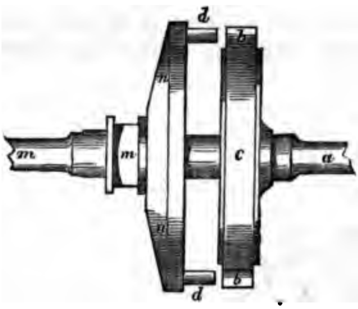


fig. 193.

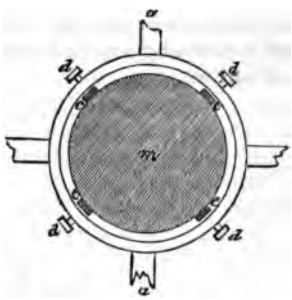


fig. 194.

engaging and disengaging machinery is illustrated in fig. 193. A pulley is fixed on the end of the shaft *a*; this being tightly embraced by a friction-band *c*, projecting snugs *b b* are placed on the periphery of the band; a clutch and cross-piece *n n*, on the shaft *m*, has projections, or prongs, *d d*; on the clutch being moved along the shaft *m* by the lever, the prongs *d d* catch the snugs *b b* on the friction-band; this slips round on the pulley, till the friction becomes equal to the resistance, and the shaft gradually attains the motion of the clutch. A modification of this method is exemplified in the "friction-wheels." Let *a a*, fig. 194, be

the pulley or wheel which is capable of being set in and out of gear by any of the methods we have shown; the eye of this is made as large as possible; in the inside of this small pieces of brass *c c* are fixed in such positions that pinching screws *d d*, pressing upon them, are placed between the arms of the wheel or pulley. On the shaft to be driven a boss or friction-wheel is accurately turned, so as to fit the eye of the wheel *a a*; by means of the screw *d d*, the brasses *c c* are made to press on the surface of *m*, and are so adjusted that the friction created is equal to the resistance offered by the wheel: as soon as the resistance by any means exceeds this, the wheel *a a* begins to move over the boss *m*, the shaft *m* continues its motion, and the wheel becomes stationary; thus the breakage of the teeth of the wheel or of the pulley is avoided. When machinery is suddenly stopped, or its direction is reversed, as the shaft beginning to turn the wrong way, it is necessary to have some means of stopping the motion of the driving shaft. A contrivance for effecting this is shown in fig. 195: to the clutch *a* on the shaft *m*, and the wheel *c* on the shaft *b*, projections with oblique faces are attached; these exactly fit into each other when in gear; the wheel *c* and clutch *a* are allowed to move on the shafts, the wheel *a* being capable of moving round on it; longitudinal motion, however, being prevented by two pins placed at each end as at *n n*, the clutch moves longitudinally along the shaft, but cannot revolve thereon by the intervention of the key *o*, as before described. On the clutch *a* being moved along the shaft by a lever, the faces come in contact, and the shaft *m* is moved; on the wheel *a* receiving any increase of speed or pressure, the oblique faces fall out of contact.

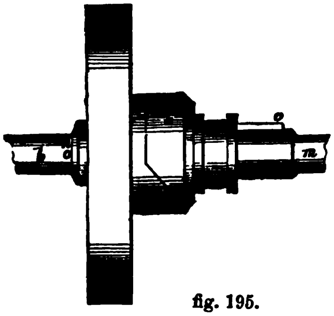


fig. 195.

CHAPTER VII.

PROCESSES AND MACHINES USED IN THE MANUFACTURE OF MACHINERY.

For the purpose of facilitating the putting together and arranging the constituent parts of machines, certain preliminary operations or processes are to be performed. The material used in their construction has to undergo certain modifications of form or shape before being fit for the special purpose of its design; hence the pattern-maker and moulder are required to produce certain parts in cast iron, the smith or forger those in malleable iron. Again, after they leave those departments, the articles are further subjected to processes having for their object the making of smooth and accurately-bored apertures, the straightening of rough and uneven into smooth and plain surfaces, the fitting of one part to another so as to insure their accurate adjustment and the easy play of the movable portions of the machines, and the turning of accurate cylindrical surfaces. The various operations here noted come under the general department of "fitting," "finishing," or "bench-work."

In giving a somewhat cursory account of the operations performed in the "Machine-shop," we shall first notice the methods employed in performing these by manual labour, and then the mechanical contrivances as substitutes for them.

The operation of drilling and boring will be first discussed. In making a small aperture in wood or other comparatively soft material, the carpenter uses a small sharp-pointed instrument termed a "sprig-bit:" partly by giving it a semi-rotatory motion, but chiefly by pressure, it is made to enter the wood; when withdrawn, an irregularly-shaped aperture is produced. A "gimlet" is used also for this purpose; it is provided with a sharp point at the end of a spiral screw. The "augur" is a modification of the gimlet, but larger; it is used for boring large holes in the timber of ships and scaffolding: to facilitate the operation, the tool has a complete continuous circular motion given to it. By means of a cross-handle of considerable length the chips are turned out in spiral pieces, and are received into a semi-cylindrical part above the spiral screw-cutting portion: this semi-cylindrical portion has one of its edges comparatively sharp; this tends to keep the interior of the perforation clean. In the contrivances above noted, different sizes of instruments are required, according to the size of aperture to be made. To obviate this inconvenience for general work, the contrivance known as "the brace and bit" is used; by this the operation of boring holes is much facilitated. A series of "bits," proportioned to the sizes of holes required, are made; the point *f*, fig. 196, enters the wood, rotatory motion is given to it, and the cutting edges *h f* cut out a circular hole. The revolving motion is given to the bit by the "brace." The cranked part *m b d* has a conical projection at *b*; this fits into a circular conical

aperture in the head *a*. The bit *c* is passed into a square hole made at *m*; the ends of the bits are all made of the same size, so that the whole set fits into *m*. The workman places the point *f* of the bit at the point in the wood where the aperture is to be made, and presses against *a* with his body, and turns the brace at the part *b*; the brace revolving at the points *b* and *m*, causes the edges of the bit to cut the aperture quickly.

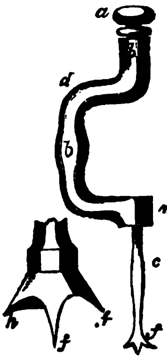


fig. 196.

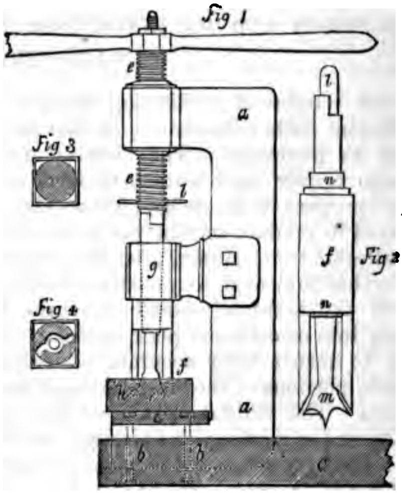


fig. 197.

Machinery is used to give a very rapid and continuous motion to the drill or bit; the most noted instance of its application for this purpose was seen during the erection of the Great Exhibition building, when many thousands of apertures were made in the sash-bars daily. A very ingenious method of making square perforations in wood, while a circular motion is used, is thus described in the *Engineer's and Mechanic's Cyclopedia*. At *a a*, fig. 197, is a strong iron frame or support, fixed by screw bits *b b* to the work-bench *c*; *d* is an octagonal iron socket, containing a brass bush, tapped to receive the vertical screw *e e*; to this screw is affixed, by a circular tenon and mortice, the square perforating instrument *f*, which accurately fits and slides up and down through a rectangular hole in a guide of brass *g*, when the screw *e* is turned by the cross-handle at top, so that the square incision is made by direct pressure downwards, at the same time that the revolving centre-bit *m* cuts out a completely round hole, the chips rising up and pressing out at the two open sides of the square cutter; *h* represents a piece of wood in the act of being bored, the dotted lines showing the depth to which the perforation has reached; a small piece of wood *i* is placed underneath, to prevent injury to the cutting-tool, by coming in contact with the cross iron plate *k*; the bolts *b b*, passing through *i* as well as *k*, secure both firmly to the bench *c*. Fig. 2 exhibits the cutting part of the instrument separately on an enlarged scale, with the lowermost portion in section: the tenon *l* is inserted into a cavity in the screw *e*, fig. 1, and made fast by a cross-

pin which goes through both; by this arrangement the instruments can be readily exchanged for others of different sizes. The lower extremity of this revolving piece is formed into a centre-bit *m*, which, owing to the collars *n n*, cannot ascend or descend without the square instrument, which accurately cuts out the angles beyond the range of the circular incision made by the former. The square cutting-tool is made of a bar of steel, with a hole drilled out of the solid, in the manner shown by the end view, fig. 3; and the edges are then formed by filing and grinding them to the bevils, shown in section at fig. 2. Fig. 4 represents a similar view of the end of the instrument with the centre-bit in its place.

We now come to notice the instruments in use for boring holes in substances of greater density than wood, as iron, brass, &c. The form of drill shown in fig. 196 would not answer for iron, &c.; the cutting edges, being too fine and fragile, would break at once. The form generally used

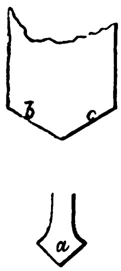


fig. 198.

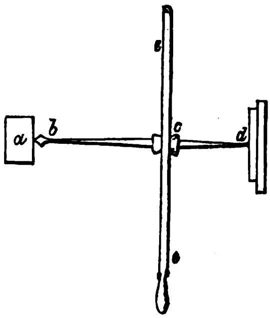


fig. 199.

is shown in fig. 198. Where the angle of the cutting edges is very acute, as at *a*, the instrument is apt to break, or at all events to produce an aperture rough and jagged in its interior, from the bit trembling or jarring; this is obviated by having the angles more obtuse, as *b c*. The angle of the cutting edges, however, varies according to the material for which the bit is designed; the angle for wrought-iron bits is different from that of bits used for making apertures in cast-iron. The obliquity of the angles should not be too great, as they then have a tendency to make the hole out of the circular. Where the holes are of small diameter, motion is given to the bit by what is called the "bow-drill," in fig. 199. The cutting edges and stock are formed in one, and provided with a small pulley *c*; the workman holds the drill horizontally, inserting the tapered end *d* in a hole made in the face of a metal plate *d*, against which he presses with his body; the end *b* bores the hole in the material *a*; an elastic bow *e e* is worked to and fro, its string or cord being passed once round the pulley *c*; a semi-rotatory motion is thus given to the drill. Continuous motion is given to the drill, by using a modification of the carpenter's brace already described. The working spindle *a a*, fig. 200, has a conical projection at *e*, working into a small hole in the under side of the lever *f g*, the fulcrum of which is at *f*—a flat bar of iron is generally used as a lever; the drill *d* is inserted at *c*, and the brace is worked

by the hand at *b*. A piece of thin sheet-iron is passed round the spindle at *b*, and prevents the necessity of its turning round in the workman's hand; the metal *h* to be bored is generally fixed in a bench vice. A modification of this contrivance is adopted sometimes, by which the lever *f* can be fixed at different elevations: one end turns upon a transverse pin, "between two uprights pierced with various holes, to allow facility of fixing it by means of the pin at different elevations; the other end of the beam traverses between two uprights, and carries a heavy weight, which, acting as a lever, necessarily keeps the drill to its work." In many cases this cannot be used; a simple lever, as in fig. 200, is then used, a hole in the wall being used as the fulcrum at *f*,

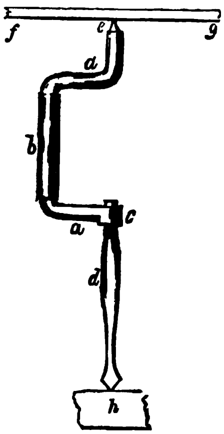


fig. 200.

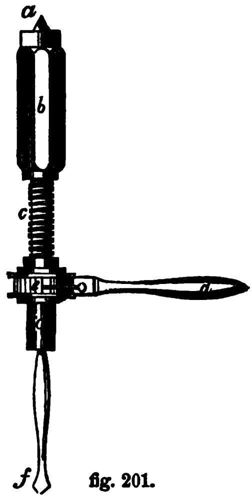


fig. 201.

the assistant bearing with the weight of his body near the end *g*. In some cases where holes are required to be drilled in machinery, it is impossible to have space in which to turn the brace completely round; the ingenious contrivance in fig. 201 is then used; it is also used in many other cases, as the effective power applied to it is always acting at a great advantage. It is made in two parts: the nut *a b* has a projection *a* at its upper end, as in the brace last described; the lower part of it has an internal screw, into which the screw *c c* works; the handle *d* is fixed on *c c*, part of it is cut out to allow a ratchet *e* to be properly fastened on it; to the handle a small click is placed, and kept in contact with the teeth of the ratchet by means of a spring. By putting the drill *f* and the conical projection at *a* in their places, and applying the pressure at *a*, an intermittent circular motion is given to the drill as follows:—On moving the handle *d* in a certain direction, corresponding to that which the cutting edges of the drill ought to have to be effective, the catch turns the ratchet-wheel, and thereby with it the spindle *c c* and drill *f*; by thus moving the nut *b*, the drill is kept to its work. By giving motion to the drill-spindle *a b*, fig. 202, by means of the bevil-wheels, the shaft *c* being turned by a winch or handle, holes may be rapidly

drilled. This motion is used in the "portable drill" of Mr. Nasmyth, the arrangement of which is given in fig. 203; where *c c* is a cast-iron

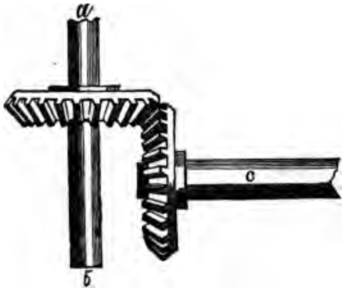


fig. 202.

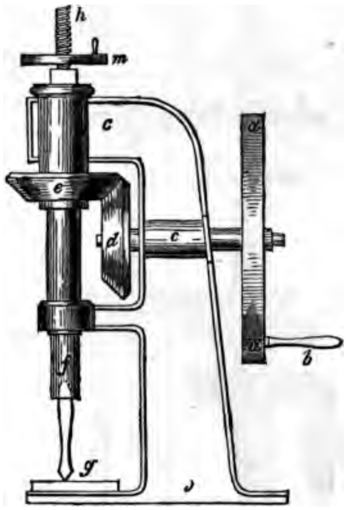


fig. 203.

frame, *a a* a fly-wheel turned by the handle *b* giving motion to the wheel *d*, which working into *e*, gives a rapid rotatory motion to the drill *f*; the drill is advanced as the perforation in *g* increases, by turning the wheel and screw *h m*. In another modification of the drilling machine by the same gentleman, the downward pressure to the drill is given by the foot of the workman pressing on a foot-board in front of the machine. This acts on a lever at the top by means of a back vertical rod; the end of the top lever works into a sliding bearing on the top of the drill-spindle; the feed of the drill can thus be regulated at the pleasure of the operative. The table on which the article rests to be drilled can be placed at any convenient height, being movable by means of suitable gearing. The drilling machine is sometimes made self-acting; that is, not only the rotary motion of the drill, but the pressure necessary to keep it up to its work, is given by the same prime mover. We first notice one of the many methods introduced for giving the self-feeding motion. Let *a a*, fig. 204, be the drill-spindle, revolving on bearings at *d e*; motion is given to it through the wheel *c*, and *b* on the driving-shaft *a*. Immediately above the lower bearing *d*, a small pinion is fixed; this works into a wheel *n*; the shaft of this is continued upwards, and is provided with a pinion *o* working into a wheel *h h*; this latter is fixed on the end of a drill-spindle, which is there screwed. The bush or centre of *h h* forms the nut, working the screwed portion of the spindle; the wheel *n* is provided with a clutch *m*, and vertical lever *n*; by this means, by moving the lever up, the wheel can be thrown out of gear with the pinion *f*, thus stopping the downward pressure of the drill. In fig. 205

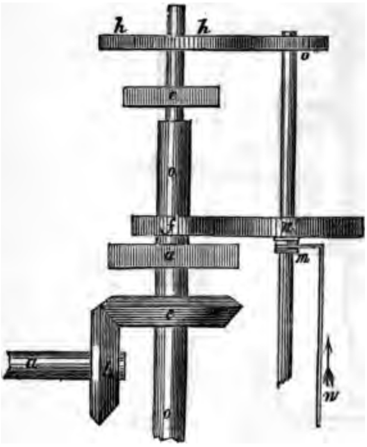


fig. 204.

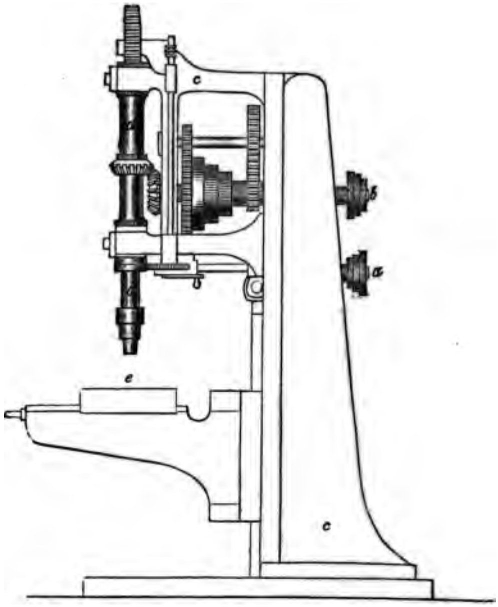


fig. 205.

we give the elevation of a self-acting drilling machine by Whitworth of Manchester: *a b* the speed pulleys, *c c* the framing, *o o* the drill, *e* the table on which the article to be drilled is placed.

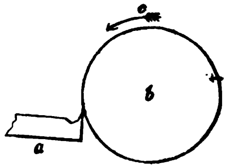


fig. 206.

We shall now notice the operation of turning. Suppose *b* to be a rod of iron turning continuously in the direction of the arrow *c*, fig. 206; and a cutting tool to be held at *a* in contact with its outer surface. It is evident that the strips of metal taken off by the tool *a* would leave the surface of *b* perfectly cylindrical. In fig. 207 we give the elevation of a "foot-lathe;" that is, where the actuating power is the pressure of the foot on the board 4, the centres of oscillation of which are at *5 5*; the up-and-down motion of the board is changed into a continuous circular motion by the connecting-rod 3, crank 2, and crank-shaft *v v*, and fly-wheel 6 6. The "fixed head-stock" is *o o*, the movable or "shifting" one at *b*; the spindle and pulley *t t* revolve in a bearing on one side of *o*, the other on a pinching-screw *s s*; the motion of the fly-wheel is imparted to the pulley on *t t* by means of a cord or band; *m* is a circular piece of metal called the "chuck;" the "centre" *n* is placed in an aperture in the centre of this. A ring with projecting end is placed round the article to be turned, as *g g*; the end of this ring catches the chuck, the motion whereof is thus given to *g g*; the other *extremity* of *g* revolves on a centre *f*, which is moved out and in *by the wheel e in the* screwed spindle *d*; the "shifting head-stock" is

moved along the top parallel slides of the lathe, and is fixed at any

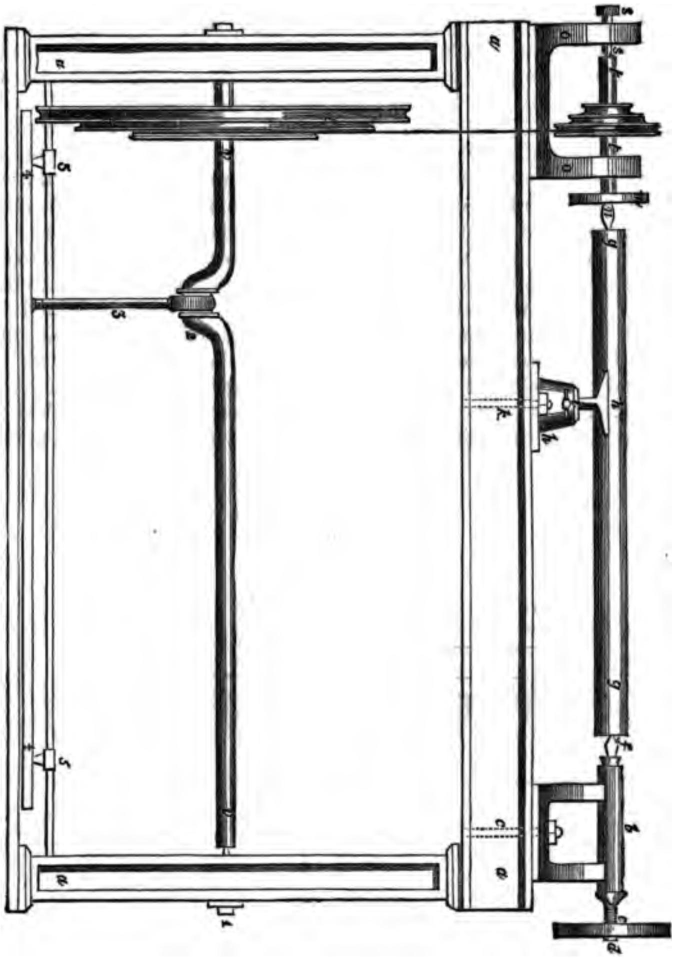


fig. 207.

desired distance from *o o* by the bolt and nut *c*. The "rest" *h'*, for supporting the cutting tool *h*, is fixed by a small pinching screw *i*; the rest is fixed at any desirable part of the lathe by means of the bolt and nut *k*. In this simple form of lathe the cutting tool is held by hand; in the improved machines, the tool is placed on and kept in one position by a contrivance called a "slide-rest." The introduction of the slide-rest opened up a new era in the art of making machinery. "It is not, indeed, saying at all too much," remarks Mr. Nasmyth in an excellent essay on tools, "to state that its influence in improving, and so extending the use of machinery, has been as great as that produced by the improvement of the steam-engine in respect to perfecting manufactures and extending commerce; inasmuch as without the

aid of the vast accession to our power of producing perfect mechanism which it at once supplied, we could never have worked out into practical and profitable forms the conceptions of those master-minds who, during the last half-century, have so successfully pioneered the way for mankind ever after attaining the otherwise latent treasures of the material world, even although opposed by time, space, and the elements. . . . The STEAM-ENGINE itself, which supplies us with such unbounded POWER, owes its present perfection to this admirable means of giving to metallic objects the most precise and perfect geometrical forms. How could we, for instance, have good steam-engines if we had not the means of boring out a true cylinder, or turning a piston-rod, or planing a valve-face? It is this ALONE which has furnished us with the means of carrying into practice the accumulated results of scientific investigation in mechanical subjects." The rationale of the principle will be best explained in the words of the same eminent authority. Instead of the workman holding the tool in his hands, let us suppose that he had it bolted firmly to the rest, "and that while it was cutting a shaving from the bar in the lathe, he had the means of SLIDING THE REST WITH ITS TOOL along the bed of the lathe, parallel to the axis of the work; it is evident that, in so doing, we

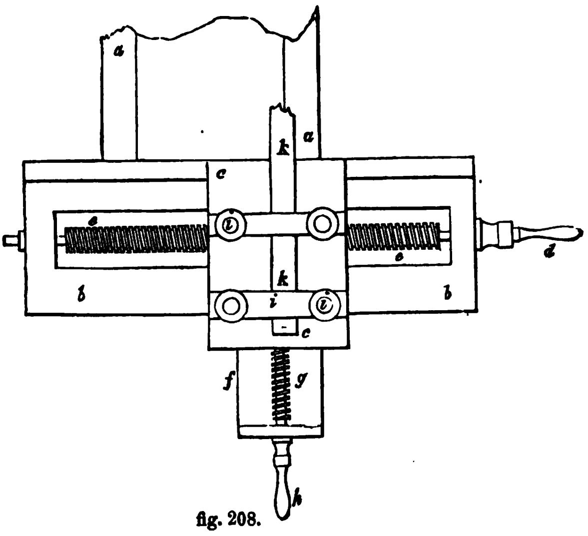


fig. 208.

should be able to turn the bar quite true; and if a screw was provided for the purpose of giving this sliding motion, we should then have a SLIDE-REST: exactly in such a manner was this truly admirable tool introduced in the mechanical world." Thus, in fig. 208, let *a a* be part of the rest bolted to the "shears;" the table *c c* moves along *b b* by means of the screw *e e*, turned by the handle *d*; the tool *k* is kept fast in its place by the cross-bars and nuts *i i*; the tool is advanced to the article in the lathe, according to the depth of cut required, by means of the screw *g*, turned by the handle *h*; when the depth of cut is adjusted by the screw *g*, the slide *c c* and its accompanying tool can be moved along the article to be turned by the

handle *d*. This can be rendered completely SELF-ACTING as follows: on the end of the screw *e e*, in place of the handle *d*, fix a toothed ratchet-wheel *c c d*, fig. 209; on the end of the turning article *b b* fix firmly a piece of iron having a projecting finger; this coming in contact with one tooth of the ratchet each revolution of *b b*, the screw *e e*, fig. 208, will revolve and move the tool along a certain distance. In large lathes, the whole of the movements are derived from a prime mover, as a steam-engine. In fig. 210 we illustrate a late improvement in lathes introduced by the celebrated mechanician, Mr. Joseph Whitworth; it is called the "duplex lathe:" part of the lathe-bed is at *m m*; the guide-screw for moving the rest along the length of

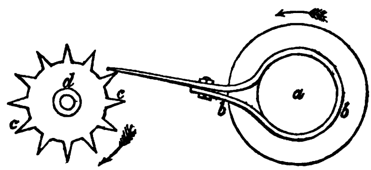


fig. 209.

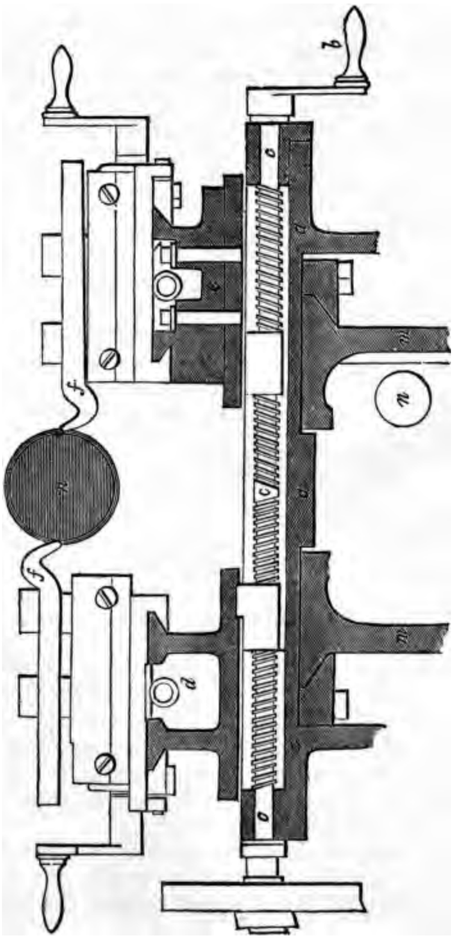


fig. 210.

lathe is shown at *n*; *a a a* the bottom slide-rest; upon this the compound slide-rest *e* is carried; *d* is a similar rest at the other side of the lathe; the tools *f f* are advanced to, or made to recede from, the article *n* to be turned by the right and left screw *c c c*, worked by the handle *b*; the tools are thus acted upon simultaneously. "Not only is double the work performed by this lathe as compared with the common single-cut plan, but it is accomplished with a less expenditure of power, owing to the saving by the lessened pressure against the stay. The work is also executed in a superior manner, there being a perfect balance of forces, and consequently all vibration is done away with; and from the greater durability of the tools so applied, only one-half the usual amount of error arises from wear."

Where metallic surfaces are to be made smooth and level, the operation of "chipping" and "filing" is performed. The former method consists in removing the rough outer portion by means of a hammer and chisel, much in the same way as a mason levels the surface of a stone with his mallet and tool. The latter is sufficiently indicated by the name. As may be supposed, the rendering of a large surface to a true plane by these manual operations is a matter of some difficulty, and one which involves much time. Indeed, accurate surfaces are scarcely attainable by hand processes; machinery has come to the aid of the mechanic in this department. The illustration in fig. 211 will explain the rationale of machine planing, by which plane metallic surfaces are obtained with undeviating accuracy and remarkable celerity, as compared with the manual processes of "chipping" and "filing." Suppose *a a a* to be a movable carriage, capable of being moved to and fro horizontally in the direction of the arrows *m m* at a certain speed, and with great accuracy of adjustment; let *b b* be the article to be planed, firmly secured to the lower table; let the tool *c*, with cutting edge *c′*, be fixed in a "holder" above the table, and capable of adjustment by suitable means in two directions, namely, from side to side, as shown by the arrows *o o* and vertically: the first motion moves the tool across the breadth of the article to be planed; the last brings the cutting edge nearer to the metal, in order to take a deeper cut, or the converse. Now if the whole is accurately adjusted, and the carriage *a* moves towards the left hand, the tool will plane or pare away a certain portion of the surface of *b b*. Now suppose the tool to have reached the end of the article, the table *a* takes a quick return motion towards the right; the tool in the meantime being adjusted to its proper place, ready to take another cut, on the table being again moved to the left. In large planing-machines, all these movements are made by ingenious machinery to be self-acting.

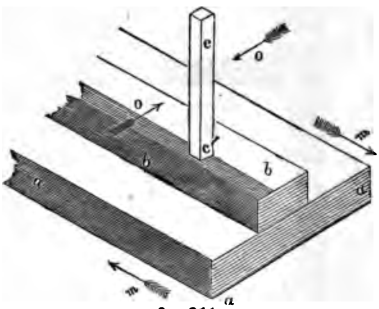


fig. 211.

In a form of planing machine now much used, a reciprocating motion *is given to the table* on which the article to be planed rests, in the following *manner.* *A horizontal* disc is placed beneath the table, and worked

by hand or power by bevil-gearing; a groove or slot is cut quite across the face of the disc, a link is connected at one end with the under side of the sliding-table, and a pin at the other is fixed at any desired part of the groove in the disc. The revolution of the grooved disc causes a reciprocating motion of the table, proportioned to the distance from the centre of the disc at which the pin is placed. A method of giving the "feed-motion" to the tool-holder is as follows. A small projecting stud is fixed at any desired place in a groove or slot in the side of the table, extending along its length. This stud presses against a movable lever, keyed on the end of a shaft which carries another lever; this acts upon the teeth of a ratchet-wheel, fixed on the end of the horizontal screw which actuates the tool-holder. In planing machines where the tool cuts while the table moves only in one direction, it is of importance to bring the table back again, in readiness for another cut, with considerable speed. If the return stroke, as it is called, is made at the same speed as the cutting one, it is obvious that much time will be unnecessarily lost; to obviate this, many contrivances have been employed. A description of one of these will suffice for our purpose. It is the arrangement employed in one class of their machines by Messrs. Nasmyth and Co.

A hollow shaft has a pulley fixed on it, near its extreme end and close to the first pulley a second revolves freely; through this shaft another shaft is passed, having at its extremity a pulley keyed on; the three pulleys are thus close together; the centre is merely used to carry the driving-belt when the machine is not in use. The first pulley drives the hollow shaft, the second the central shaft; at the end of the hollow shaft furthest from the pulleys a pinion is keyed on; this works into a wheel, this wheel is keyed on the shaft which carries the pinion working into the rack, which moves the table forward. On the end of the central shaft a small pinion is also keyed; this works into an intermediate wheel, which in its turn gives motion to a wheel fixed in the rack-pinion shaft. When the driving-belt is applied to the pulley on the hollow shaft, the table is moved forward; when it has reached to the end of the cut, the belt is moved to the pulley on the central shaft, and the table is reversed; its return stroke being so much quicker than the forward one, just in proportion to the difference between the size of the wheels on the rack-pinion shaft.

In various parts of machines grooves or slots are frequently required to be cut in some part; thus in cutting the key-seat in the centre eye of a wheel, as in fig. 103, when done by hand, the size of the groove is first marked, and the metal cut out of the solid by means of the chisel; this is afterwards filed up to the proper shape. When machines are used to perform this operation they are termed "slotting machines," and may be defined as a modification of the planing-machine, with movable tools.

In the illustration in fig. 212, suppose *d d* to be a piece of metal in which a groove *e* is to be cut; *c c* the table to which it is fixed during the operation; *f f* a vertical guide, with a groove *g* in its face. In this groove a cutting-tool *a b* slides up and down. Suppose the whole to be adjusted, so that when the tool is made to descend in the guide *g* by appropriate means, its edge will pare a thin cut off the edge of the metal *d d*; the tool is then raised up in the groove *g*; but before it descends, the metal *d d* is moved forward, so that another portion is subjected to the

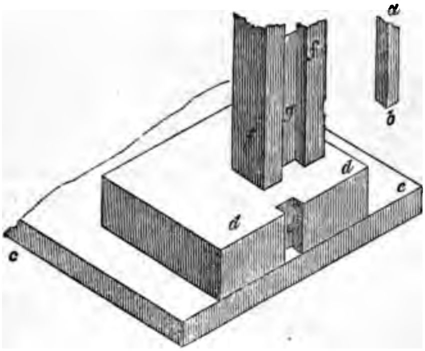


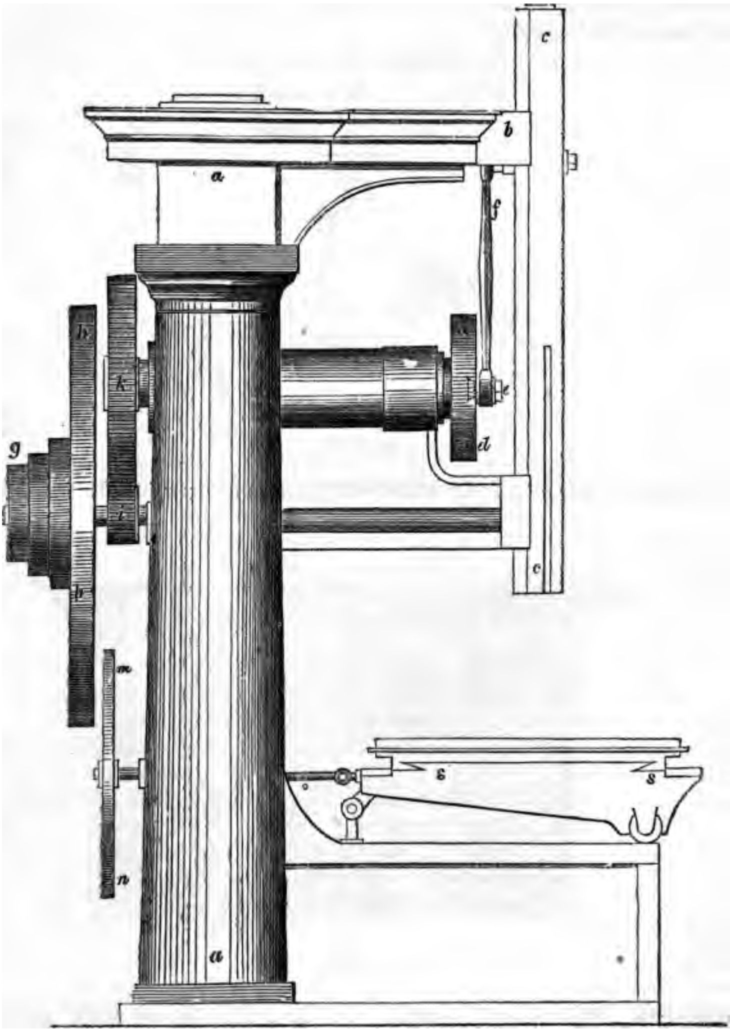
fig. 212.

cutting edge. Thus, by alternately raising and depressing the tool, and moving the article to be cut regularly forward to meet the cutting-edge, a groove of any depth can be cut in the metal, the breadth of which is obviously equal to the width of the cutting-tool, and the length to the thickness of the metal in which the groove is to be cut.

In fig. 213 we give an elevation of a slotting-machine, where *a a b* is the framing; *c c* the vertical guide-bar in which the cutting-tool slides up and down; *s s* the table on which the article to be grooved is placed: it is moved to and fro on the under part of the framing by the wheel and screw *m m o*; *g* is the driving speed-pulley; *h h* the fly-wheel, giving motion by the toothed wheels *i*, *k* to the eccentric *d d*, to the face of which the connecting-rod *f* is attached by the pin and nut *e*. The way in which the reciprocating motion of the cutting-tool is kept up will now be familiar to the reader on inspection of the drawing: its rationale is described in figs. 167 and 173.

Where a number of holes are required in malleable iron plates, they are made by what is called the "punching-machine." Suppose *d*, fig. 214, to be a fixed table, on which a rest *a* is fixed by bolts *b b*; this rest has an aperture sunk in its surface, or a hole bored through and through it in the direction of its length. A punch *f* is attached to *e*, which has a vertical reciprocating motion given to it. If a plate of iron is placed on the rest *a*, and the punch *f* made to descend with sufficient force, a portion of the metal is forced out, making a circular aperture corresponding to the diameter of the punch. The punching-machine employed at the erection of the building for the Great Exhibition of 1851 perforated 3000 holes in a day. Some of these machines in use in the workshops of engineers are of such great power, that holes one inch in diameter can be made through plates of iron three-quarters of an inch thick, with as much apparent ease as the grocer cuts a hole in tasting the merits of a cheese.

In dividing plates and bars of malleable iron by HAND, the line of direction is first traced on the surface, then, by laborious applications of the hammer and chisel, the plate is divided. The blacksmith in cutting a bar asunder places it on a sharp-edged instrument fixed at one end of his anvil, and the heavy tilt-hammer strikes the upper side of the bar till it is divided. In the "shearing-machine," the iron to be divided is placed upon a sharp cutting edge *b b*, fig. 215, fixed by bolts *c c* to the lower table *m m*; the upper cutting-tool *a a* is fastened to *d d*, which has an up-and-down motion; the down motion cuts the plate placed on *b b*. In fig. 216 a simple shearing-machine is shown: *h* the metal to be cut, placed between the cutting-edges *f g*; the upper edge *f* is



fi.;. 213.

part of a lever *f d d*, vibrating on the centre *e*; a reciprocating motion is given to the lever *d* by the eccentric wheel *a b* and friction-pulley *c*. In fig. 217, which is a patent punching and shearing machine by Mr. Roberts of Manchester, the up-and-down motion of the cutting-tool *g′ f f* is given by means of the eccentric wheel and rod *f f*. The driving-shaft is at *a a*; *c c* the fast-and-loose driving-pulleys; *b b* the fly-wheel; *d* a pinion fixed on the fly-wheel shaft, working into the

wheel *e e*, which gives motion to the eccentric shaft; *h i* is the "punching" part of the machine.

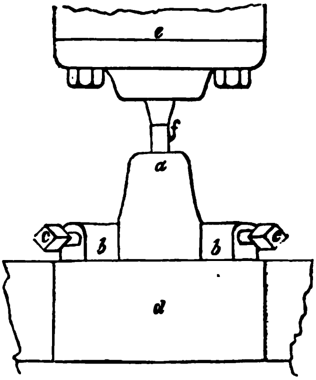


fig. 214.

In making screw-bolts by hand two methods are employed: first, the

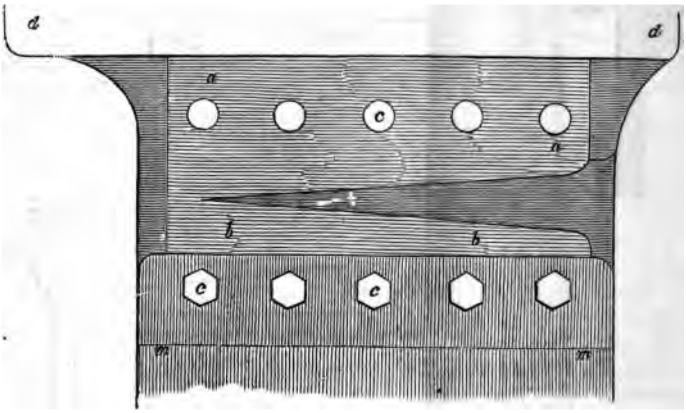


fig. 215.

screw-plate which, in its simplest state, is a flat piece of metal, as *a b*,

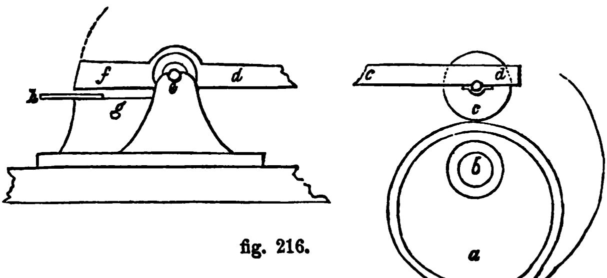


fig. 216.

fig. 218, in which are made a series of graduated screw-holes; by passing the circular rod of iron first through the largest hole, and successively to the smallest, the finished screw is obtained; the handle *b* is used for

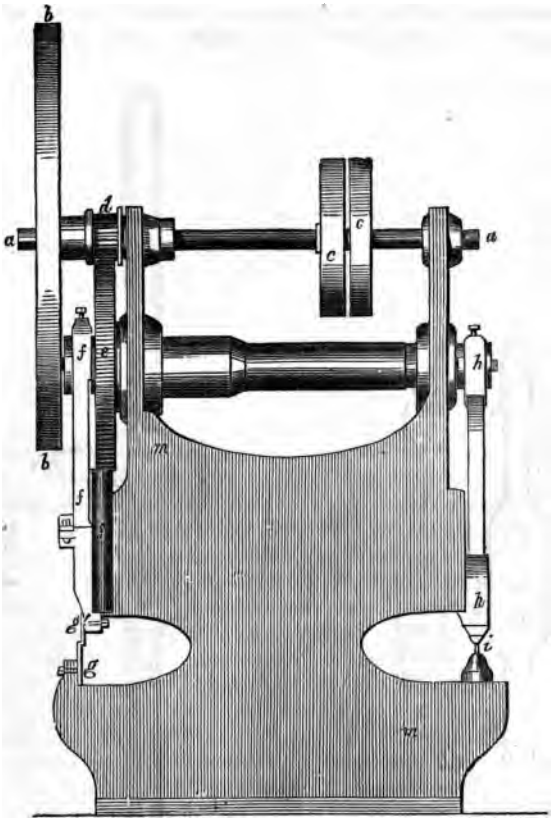


fig. 217.

working the screw-plate; this form is chiefly used for small work. At *e e* another form for larger screws is shown. It is obvious that for each distinct size of screw-bolt to be made, a screw-plate will be required. To obviate this inconvenience, and to obtain from one plate different sizes, the contrivance called the "screw-stock" is used. In this, movable dies for cutting the screw are employed, a small pinching-screw being used to bring them close up to the bolt as the cutting proceeds. The most improved form of screw-stock is that known as Whitworth's "guide-stock." It is shown in fig. 219; *d d* are the handle-levers by which the stock is worked; *c c c* the cutting-dies, one of which at the centre is fixed, the other two are movable by the pressure of the screw-nut *b b*; so that they embrace closer as the work proceeds. The bolt to be screwed is placed at *a*. This form of screw-stock is a great improvement on the old. "The

steadiness of the guide-stock, and its easy action in screwing, are equally remarkable. In using it, not one half the force consumed by the common stock is required. The inner edges of the moving dies, which act principally in cutting out the metal, are filed off to an acute angle; this enables them to cut with extreme ease, and without in any degree destroying the thread, while they take off shavings similar to those cut in the

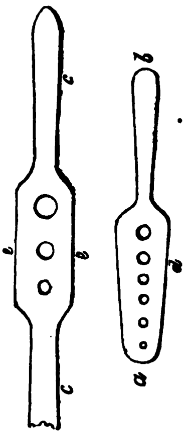


fig. 218.

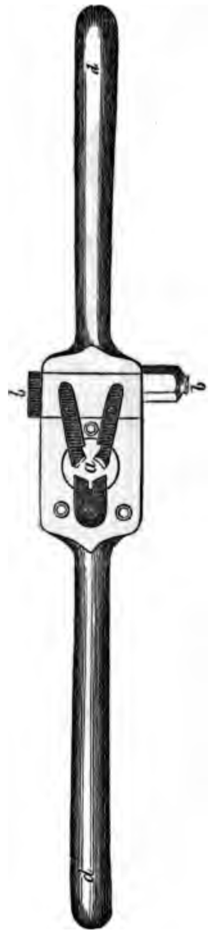


fig. 219.

lathe." Nuts are screwed on the inside, so as to fit their particular bolts, by what is called a "tap," having on its surface a screw cut, with pitch corresponding to the dies which cut the thread of the bolts. The form of tap generally used is tapered, the lower end being filed or turned so as to reduce the depth of cutting-edges; this enables the tap to enter the nut freely, and gradually cuts the thread deeper and deeper as the tap advances in the direction of its length; two or three circular grooves are cut along

the length of the tap; these form channels by which the tool clears itself of the cut metal. The end of the tap is square-headed. This is taken hold of by a lever, which serves as the moving power to turn the tap while working. The method of cutting screws by machinery will be understood by the following diagram, fig. 220. Suppose *a a* to be a cylindrical bar of iron, on the surface of which a screw is to be cut, and revolving in a lathe; *c d* a tool-holder and tool, the latter in contact with the cylinder *a a*, the former moved along the guide-screw *b b*. Now, if a toothed wheel be fixed on *a a*, working into another fixed on the guide screw *b b*; the tool *d* will be made to move along the surface of the revolving cylinder *a a*, and trace out thereon a spiral thread or groove. By arranging the relative proportion of the toothed wheels, a screw of any desired pitch may be cut in the bar *a a*; then suppose the guide-screw to have eight threads in one longitudinal inch, each revolution of the guide-screw will move the tool *d* forward an eighth of an inch; thus, if the driving wheel on *a a* is equal in diameter to the driven wheel on *b b*, a screw will be cut on *a a* having a pitch equal to that on *b b*; but if the driving wheel on *a a* is double that on *b b*, then the pitch on *a a* will be double that on *b b*, as, for each revolution of *a a*, *b b* will make two. But, on consideration, it will be seen that the direction of the thread cut on *a a* will be the reverse of that on *b b*; thus, if the latter is a right-handed screw, that on *a a* will be left-handed, from the circumstance of the cylinder *a a* and guide-screw *b b* revolving in contrary directions. To obviate this inconvenience, intermediate wheels, gearing with those on the cylinder and guide-screw, are used. In practice, the driving and driven wheels are placed towards the left hand of the lathe, the driving-wheel being fixed on the lathe-spindle, the cylinder to be screwed being fastened to the centre-point and chuck in the usual way.

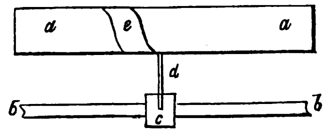


fig. 220.

For making small screw-bolts the lathe is superseded by the "screwing and tapping machine," of which the following description will suffice to make the principle of its operation understood. The bolt to be screwed is placed in a chuck *a*, fig. 221, fixed at the end of the lathe-spindle; the dies are placed on a frame *c*, which travels on two parallel bars *d*; the dies are made to embrace the bolt to be screwed, so as to have sufficient hold of its surface; it is then made to revolve, which causes the frame with the dies to traverse along the bolt. On the die-frame being made to traverse as far as required on the bolt, the driven wheel *e* on the lathe-spindle is thrown out of gear with the driving-wheel *f* by means of a clutch and lever *g*; at the same time, the other end of the clutch locks into another wheel *m*, and this again gears into another *n*; by this means the lathe-spindle and bolt is reversed, and the die-frame moves on the parallel bars outward from the bolt; as it is essential to save time in the return or reverse motion of the die-frame, this is effected by the increase of diameter of the wheel *m*, gearing into that which reverses the lathe-spindle *n* over *f*, that which gives the direct motion thereto. By substituting a tap in the lathe-chuck for the cylinder to be screwed, and fixing a

nut in the die-frame, it is obvious that on the tap catching the nut, it

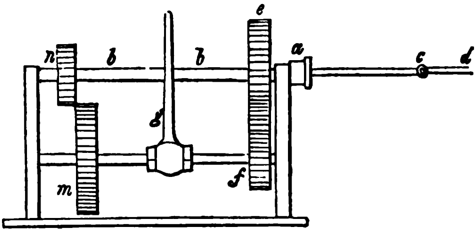


fig. 221.

would be pulled forward by the revolution of the tap, and its interior screwed. Nuts are made of different shapes, square, hexagonal, or octagonal. In finishing them, so as to bring their sides square, flat, and polished, by hand, they are placed in a vice, and by means of the hammer and chisel are first brought to a comparatively flat surface; they are then rough filed, next smooth filed, and brought to a polish when perfectly flat by means of emery and oil. This operation is a tedious one, and moreover expensive, when the nuts are numerous; machines have, therefore, in large establishments been employed to cut the faces of nuts and bring them rapidly to true surfaces. In an efficient form of "nut-cutting machine," the faces of the nuts are cut by the action of a revolving cutter fixed at the end of the spindle of the fixed head; the nut is placed on a table capable of being moved forward to meet the cutter, by means of a handle, wheel, and screw. The different faces of the nut are presented at the required intervals by causing the table on which it is supported to revolve horizontally for a certain definite distance, it being retained in this position till the face is cut by means of a spring-catch fitting into notches in the periphery of the lower part of the table. The feed-motion of the table can be made self-acting by simple means: corresponding speed-pulleys are fixed, one at the end of the driving spindle which moves the cutter, the other on a horizontal shaft placed beneath the table, and extending along the side of the machine; at the end of this shaft, and immediately beneath the table on which the nut to be cut is fixed, a small worm or endless screw works into a toothed wheel; on the shaft of this is a small pinion, which gears into a rack placed in the lower part of the table.

Rivets are used in mechanical operations for tightly securing plates

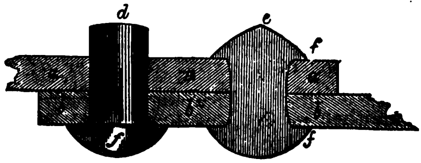


fig. 222.

together, as the edges of boiler-plates: thus, suppose *a a*, *b b*, fig. 222, to be the edges of two boiler-plates; holes are punched in each, so that when the plates are laid together the holes will correspond; rivets made

of malleable iron, and circular, are passed through the holes; they are longer than the combined thickness of the two plates; the rivets are passed through the holes red-hot, and while one man holds tightly on with a hammer, pressing on the part *f*, one or more workmen hammer quickly on the part *d*, and speedily bring the head into the shape as shown at *e f*. The noise produced by this process is very great, especially

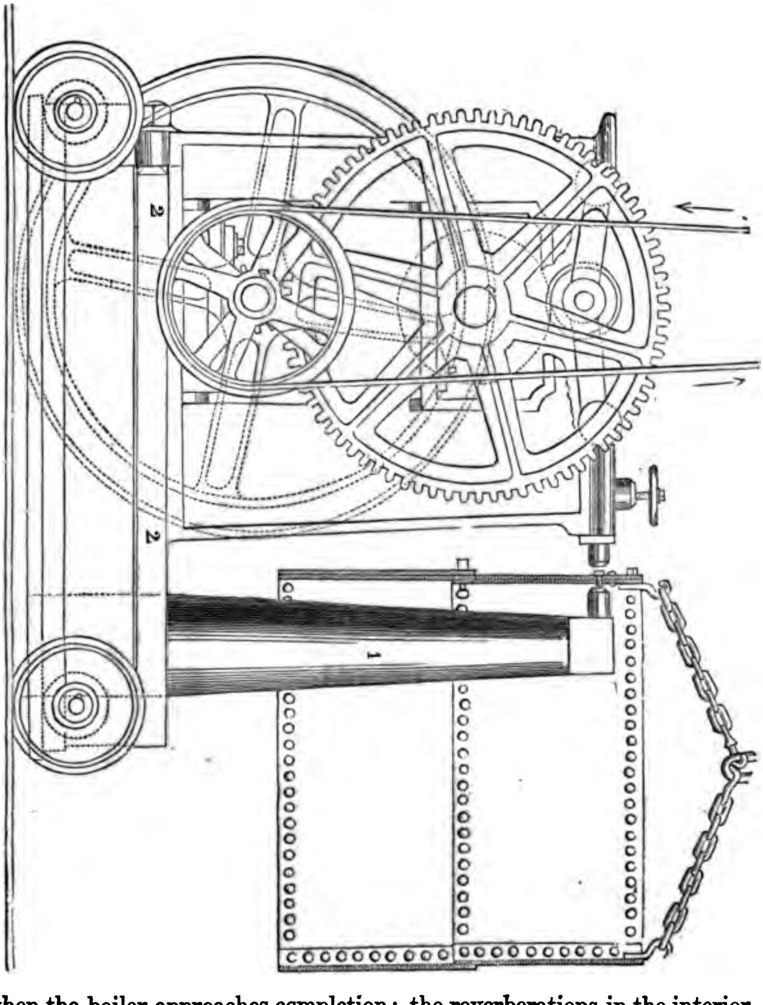


fig. 223.

when the boiler approaches completion; the reverberations in the interior adding to the noise of the repeated blows on the ringing metal. There are many objections to riveting by hand; it is tedious and costly; moreover, from the repeated blows given to the rivets, the iron is crystallised, and the heads are apt to break off. Steam machinery is now largely employed for riveting. The "steam riveting machine" was first intro-

duced by Mr. Fairbairn, of Manchester; we give an elevation of it in fig. 223. The principle of the machine is that of the rule-joint lever; a revolving cam gives motion to this lever, at the extremity of which the ferule for compressing the rivet is fixed. This machine is quite

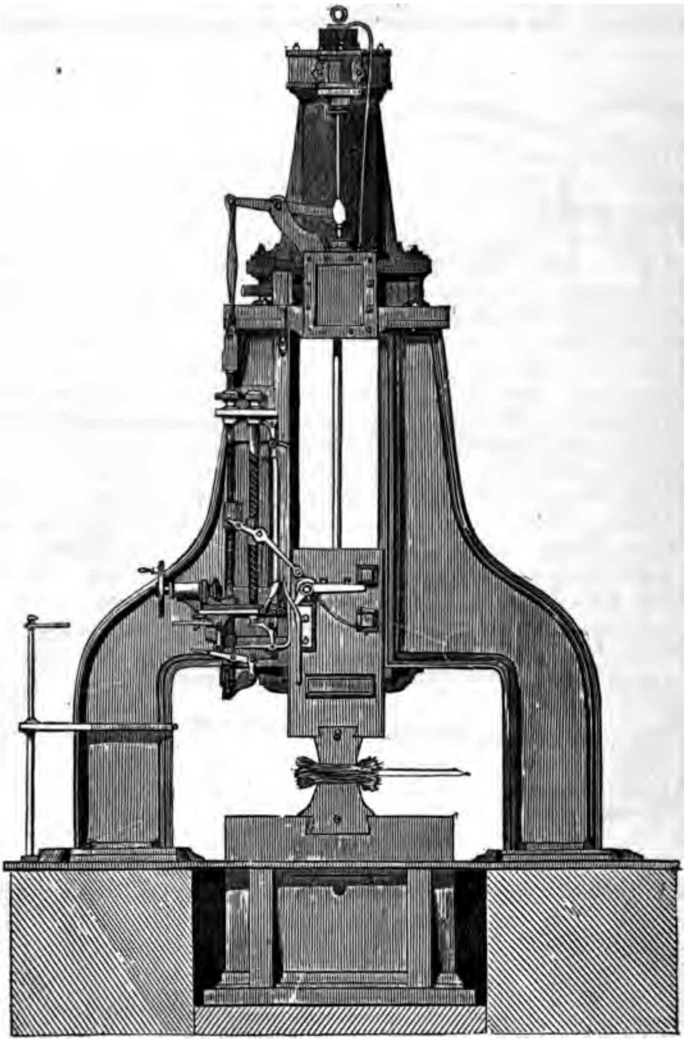


fig. 224.

noiseless in its operation; it acts by compressing the iron while hot; it is capable of fixing, in the firmest manner, eight rivets three-quarter inch diameter in a minute, with the attendance of two men and two boys to the plates and rivets, whereas the average work that can be done by

two riveters, with one "holder on" and a boy, is forty similar rivets per hour; the increase in quantity of work done by the machine being at the rate of twelve to one, exclusive of the saving of one man's labour. The riveting dies are of various descriptions, adapted to every description of flat or curved work; even the corners are riveted with the same ease as other parts, so that vessels of any shape may be completed without recourse to the old hammering process. Messrs. Garforth of Dukinfield exhibited in the Crystal Palace a steam riveting machine, capable of being worked at a high speed. The pressure of the steam is applied directly to give the compression to the rivet; the cylinder is horizontal, and the die is fixed to the end of the piston-rod; to get the desired pressure a large cylinder must be used, as there is no mechanical contrivance adopted between the point of power and that of resistance; hence the expenditure of fuel and steam must be very considerable; they are nevertheless coming rapidly into use.

The forging of large and small pieces of iron into proper shapes by means of machinery is fast superseding, for many kinds of work, the costly and tedious manual labour of the "blacksmith" and "forger." The method of bringing red-hot masses of iron into shape by means of the anvil and hammer is too well known to need description. The "steam hammer" of Nasmyth (fig. 224) is the most perfect and controllable of any yet introduced for forging large articles. In this steam hammer the piston-rod *a* of an inverted high-pressure cylinder *b* is attached to a mass of cast iron *c*, sliding between two upright guides. The steam is let in *under* the piston of the cylinder, which is lifted up together with its attached hammer-block to any required height, when by its own motion the steam is allowed to escape, and down comes the hammer with vast energy on any substance placed on the anvil *d*. By the controlling machinery at *e*, the height of the fall, as well as the velocity, may be so completely controlled, as to bring the hammer down with its full power, or so gently as merely to drive in a nail.

THE END.

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